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

Vol. XV No. 12 DECEMBER, 1955

SPECIALIST EXHIBITIONS

Contemporary British journals are again commenting on the wide range of exhibitions planned as a "shop window" for the products of the radio and electronics engineer. The participation of manufacturers in any exhibition is mainly a commercial policy decision, but from the viewpoint of the engineer, exhibitions form an effective "mirror of progress"—which was the subject of an editorial in the June 1953 issue of the *J.Brit.I.R.E.*

Current opinion has added little to the view already expressed that there is a need for an exhibition of electronic and radio equipment as distinct from domestic apparatus, which forms the main theme of the annual National Radio Show. That exhibition is not completely effective as a demonstration of the electronic equipment designed for industrial use, or of the communication equipment essential to the aircraft industry and the Services.

Opinions expressed in contemporary radio journals now agree that the present National Radio Show, whilst retaining its emphasis on radio and television reception, should be expanded. This may well require a separate exhibition, not necessarily to be held at the same time and place as the domestic show. The use of radio and electronics in ways other than for entertainment could then be more fully exhibited, instead of demonstrating such equipment as a subsidiary attraction. Although an electronics exhibition would cover a wide field, it should be possible to organize it on a sectional basis, e.g. components, radar, automation and other industrial applications, which would be helpful to the specialist visitor.

It is estimated that the annual turnover of the radio, electronics and telecommunications industry in Great Britain is £250,000,000 per annum. Before the war, 90 per cent. of the products of the radio component industry went into domestic radio and television equipment: now, only 45 per cent. of component production is used in this field—an indication of the fact that the manufacture of radio and television receivers now forms a very much smaller part of the work of the entire industry.

The British radio and allied industry now employs 200,000 people. It is not known how many engineers are included in this number, but a recent survey of the Institution's membership showed that the majority of members are not wholly engaged in the engineering of domestic products.

A professional exhibition as now envisaged would, therefore, afford an opportunity of showing how the radio and electronics engineer is contributing to the development and efficiency of other industries, including atomic energy development. It would also emphasize that radio is an integral and essential factor in the development of communications in all fields, particularly in the Defence Services.

The Automation and Electronics Bill at present before the House of Commons provides for the setting up of a Committee to consider "the social, educational, cultural, and economic needs and consequences of the application of automation and electronic devices to British industry": it reflects but one of the reasons why there is a need for the specialist exhibition.

NOTICES

Obituary

The Council has learnt with regret of the death of Ralf Schloss, on November 2nd while on military reserve duty with the Israeli Army. Mr. Schloss, who was elected a Graduate of the Institution in 1954 after passing all parts of the examination, was with the Palestine Electric Corporation at Tel Aviv, being concerned chiefly with cable measurements. He was born in Germany, and was 32 years of age.

London Section Meetings

During recent months, attendance at the London Section meetings has increased considerably, and it will be necessary to introduce special arrangements for the following meetings:—

Thursday, 5th January, 1956

Wednesday, 25th January, 1956

Members should note that it is essential that they sign the attendance book immediately on arrival at the London School of Hygiene and Tropical Medicine, that is, before going to the Refectory.

Visitors will be admitted to these meetings by ticket only, and members wishing to bring guests are therefore asked to apply to the Institution as early as possible for tickets.

New Committee of South African Section

The new Committee of the South Africa Section for the 1955-56 Session is as follows:—Chairman: D. H. Mills, B.Sc. (*Associate Member*); Vice Chairman: E. J. Middleton (*Associate Member*); Honorary Secretary: S. L. Morgan (*Associate Member*); Honorary Treasurer: L. Charlton (*Associate*); and: V. R. Krause (*Member*); B. J. S. Barnard (*Associate Member*); W. G. Denny (*Associate Member*); M. C. Dickman (*Associate Member*); B. L. D. Porritt (*Associate Member*); H. Rothenberg (*Associate Member*); A. W. R. Woods (*Associate Member*); E. C. Howes (*Associate*); J. Lapin (*Associate*); R. W. Sinclair (*Student representative*).

Correction

In the paper "Examination of the 'Negative Frequency Concept'," by A. P. Bolle and J. L. Bordewijk (November *Journal*) the equation in second paragraph of Section 5 (page 585) should read:

$$i = \tfrac{1}{2}(i_I + i_{II}) = \ldots\ldots$$

Students' Essay Competition

The General Council has decided to establish an Essay Competition for Students. Each year a set subject will be announced for the Essay and the topics to be discussed will in general be those on which junior members of the Institution may be expected to have reasonable knowledge.

Entries are now invited for the first Competition, the subject of which is "Problems of Technical Training." It is the Council's desire that this should be dealt with primarily from the viewpoint of the trainee and that training in both theory and practice should be covered.

The Council will award a prize of 10 guineas for the best essay and 5 guineas for the second best; at Council's discretion additional prizes may be awarded for entries which are highly commended by the referees. These awards will replace the existing Students' Premium.

The Competition is open to all registered Students of the Institution, as well as to Graduates under the age of 23 at the closing date of the Competition, which for 1956 will be April 1st. The length of essays should *not* be more than 3,000 words, preferably, but not essentially, typewritten, on one side of the paper only. The Council reserves the right to publish outstanding contributions in the *Journal*.

Completion of Volume

This issue completes Volume 15 of the *Journal*. An index to the Volume will be distributed with the January 1956 issue.

Members wishing to have their *Journals* bound by the Institution should send the complete set of issues and index to the Institution together with a remittance of 12s. 6d.

Back Copies of the *Journal*

The Publications Department of the Institution is anxious to acquire the following back copies of the *Journal*:—

May/June 1948; November/December 1948; January 1953; March 1955; June 1955; July 1955.

Members willing to dispose of the above copies are invited to return them to the Publications Department, who will remit the cost of 5s. 0d. per copy.

Please note that these are the *only* issues which are now required.

REPORT OF THE ANNUAL GENERAL MEETING OF SUBSCRIBERS TO THE BRIT.I.R.E. BENEVOLENT FUND

(The meeting was held at the London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1, on 26th October, 1955, commencing at 7.00 p.m.)

In the absence of the President, Mr. G. A. Marriott occupied the Chair and called upon the Honorary Secretary, Mr. G. D. Clifford, to read the notice of meeting which was published in the September 1955 *Journal.*

1. To receive the Income and Expenditure Account and the Balance Sheet for the year ended March 31st, 1955.

On behalf of the Trustees, the Honorary Secretary referred to the Accounts, Balance Sheet and Auditor's Report published on page 448 of the September 1955 *Journal.*

The accounts were quite straightforward but there were two items which deserved comment, firstly that the total contributed to the Fund was higher than ever before, partly due, of course, to the very generous donation received from Sir Louis Sterling. Secondly, due to the prudent policy adopted by the Trustees in past years, a very satisfactory item of revenue was received from investments.

2. To receive the Annual Report of the Trustees.

The Chairman requested the Honorary Secretary to continue in presenting the Annual Report of the Trustees. Mr. Clifford stated that the Trustees had especially commented on the desirability of securing a larger number of contributions which would be more in keeping with the total membership of the Institution. It was an unfortunate fact that the great majority of members did not subscribe to the Benevolent Fund. A very large measure of thanks was therefore due to those members who did give support and on whose shoulders laid the main burden of maintaining the Fund. During the year there had been some new subscribers but in the main contributions came from those who had regularly given support since the Fund was started and the Trustees much hoped that more members would give financial help to this work.

In appealing to all members to make a special endeavour to give a donation, Mr. Clifford emphasized the advantage and benefit to the Fund which accrued by members completing a Deed of Covenant.

Mr. Clifford then dealt with the grants which had been made and continued: "Whilst the report given in the *Journal* details some of the cases which have been assisted by the Benevolent Fund, it is not possible to detail in a published report the personal attention and guidance which is given to applicants. The Trustees are always at pains before closing a case to ensure that members or their dependants are firmly rehabilitated and that no further help is needed. In addition, they believe that to make assistance worth while it must be given promptly; action is therefore taken with all possible speed keeping formality to a minimum, but whilst at all times ensuring that the case is deserving of help."

Mr. Clifford formally moved the adoption of the accounts and annual report of the Trustees. Many members wished to support the motion and the accounts and annual report were approved unanimously.

3. To elect the Trustees for the year 1956-57.

Mr. G. A. Marriott thanked the Trustees on behalf of subscribers for their services during the past year, and proposed that the following be elected Trustees for the coming year:—

The President of the Institution.
The Chairman of the General Council.
E. J. Emery (Member).
(for the fourth successive year)
A. H. Whiteley (Companion).
(for the sixth successive year)
G. A. Taylor (Honorary Treasurer).
G. D. Clifford (Honorary Secretary).

The proposal was carried unanimously.

4. To elect the Honorary Solicitor and the Honorary Auditor.

The Trustees recommended the re-appointment of Mr. Charles Hill and Mr. R. H. Jenkins as Honorary Solicitor and Honorary Auditor respectively. Mr. Marriott felt that all subscribers would wish to show their appreciation for this continued voluntary service to the Fund by accepting the Trustees' proposal.

The motion was approved unanimously.

5. Any other business.

The Trustees had not received notification of any other business and after thanking all subscribers for their support during the year Mr. Marriott declared the meeting closed.

PREMIUM WINNERS 1954

Frank Neville Hosband Robinson, who was born in 1925 at West Bromwich, was educated at Christ's College, Cambridge, where he received his B.A. degree. Subsequently he was, from 1945 to 1950, employed by the Admiralty in work on microwave tubes. In 1950 he was appointed a Nuffield Research Fellow at the Clarendon Laboratory, Oxford, subsequently obtaining an I.C.I. Fellowship.

During the Autumn of 1954 and Spring of 1955, Mr. Robinson was granted leave of absence from Oxford to work in the Electronics Research Department of the Bell Telephone Laboratories. He is now an English Electric Research Fellow at Oxford and is engaged in work on low temperature physics.

The Clerk Maxwell Premium was awarded to Mr. Robinson for his paper on "Microwave Shot Noise in Electron Beams and the Minimum Noise Factor of Travelling-wave Tubes and Klystrons" which was considered to be the most outstanding paper published in the *Journal* during 1954.

Terence Bernard Tomlinson was born at Farnborough, Hants, in 1922 and was educated at Kings School, Grantham, and Nottingham University. After obtaining a London B.Sc.(Hons.) degree in 1942 he became a demonstrator at the Cavendish Laboratory, Cambridge. Between 1946 and 1948 he held the position of senior television engineer at Sobell Industries. He then received an appointment as lecturer in Telecommunications and Electronics at the University of Southampton. Since May of this year he has been with the Electron Physics Group at the Research Laboratories of the General Electric Co. Ltd.

Dr. Tomlinson received his Ph.D. in 1954 for a thesis on "Low Frequency Fluctuation of Thermionic Emission," and the paper "Partition Components of Flicker Noise," for which he received the Heinrich Hertz Premium, is based on part of this research. He is the author of a number of papers and articles in the technical press.

Elected an Associate in the Institution in 1945, Dr. Tomlinson was transferred to Associate Member in 1950. From 1947 to 1951 he served as examiner for the Graduateship Examination in the subjects of Television and Radio Reception. He has recently been appointed a member of the Programme and Papers Committee.

Gerald Norman Patchett was born in Bradford in 1917 and attended the Bradford Technical College from 1934 to 1937, obtaining a London B.Sc. degree with first class honours. He then joined Bradford Corporation Electricity Department, first as a student apprentice and then as an assistant in the testing of protection equipment and standardization of instruments.

During the war he was transferred to Bradford Technical College, where he lectured to service personnel on radio subjects. After the end of the war, Dr. Patchett received an appointment as Assistant Lecturer in the Electrical Engineering Department of the College, and after holding successive posts as Senior Assistant and Senior Lecturer he became Head of the Department three years ago.

In 1946 Dr. Patchett received the Ph.D. degree of London University for his thesis on "Voltage Stabilizers with Particular Reference to the Use of Non-linear Elements in the Indicator." Dr. Patchett is the author of numerous papers and articles in professional and technical journals and also of a book on Automatic Voltage Regulators: his paper in the *Brit.I.R.E. Journal* on "A Critical Review of Synchronizing Separators with Particular Reference to Correct Interlacing" gained him the Leslie McMichael Premium for the most outstanding paper presented during 1954 on improvements in the technique of broadcast or television reception.

Elected an Associate of the Institution in 1943, Dr. Patchett was transferred to Associate Member in 1951 and to Full Member in 1954.

WIDE-BAND THREE-PHASE RC-GENERATORS FOR COMPLEX MEASUREMENTS OF TWO-POLES AND FOUR-POLES*

by

G. Thirup†

SUMMARY

From a 3-phase R-C oscillator two voltages are derived, the complex ratio of which can be varied. The complex ratio is independent of the frequency. The two voltages are used in a compensation circuit for measuring the parameters of two-poles and four-poles. Two equipments are described covering the frequency ranges 20 c/s—22 kc/s and 22 kc/s—10 Mc/s. The possible error is ± 0·5 db and ± 2° in the frequency range 100 c/s—3 Mc/s. Outside this range the phase error may increase about 3 times while the amplitude error remains nearly the same.

1. Introduction

The transfer function of a four-pole is usually measured by connecting a generator to the input terminals. The amplitude ratio and phase shift between input and output voltages are then measured either simultaneously by a compensation method or separately by voltmeters and phasemeters. Another less generally applied method is to use two generators of the same frequency, giving output voltages of which the complex ratio can be varied. The two generators of the same frequency are connected to the input and output terminals of the four-pole as shown on Fig. 1. A zero indicator is inserted in the output circuit. The complex ratio between the two generator voltages is varied until zero indication is obtained. The complex voltage ratio of the four-pole is then read from the phase and amplitude dials of the generators.

This method has the advantage of a smaller loading of the output terminals than the common methods, because either the output current or the output voltage is effectively zero. Below 10 Mc/s a broad frequency range can be covered without using mixing circuits, which makes the apparatus simpler than other comparable types of apparatus. A disadvantage is the necessity of a selective zero indicator, necessary in view of the harmonics which are always present in the output voltages of the generator.

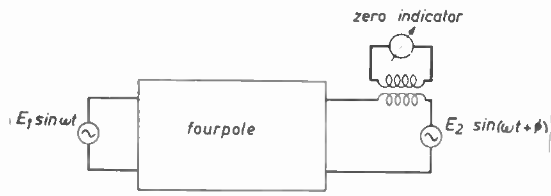


Fig. 1.—Measurement of the ratio of input and output voltage of a four-pole by means of the two-generator method.

In this paper apparatus of this kind will be described. It consists of three main parts:

(*a*) A 3-phase R-C oscillator with output voltages of equal amplitudes and differing 120 deg. in phase, to be described in Section 2.

(*b*) A voltage-adding part in which the three output voltages of the 3-phase generator are combined in such a way as to give an output voltage with a known phase angle variable over 0–360 deg. (Sect. 3).

(*c*) A calibrated attenuator without parasitic phase variation (Sect. 4).

Two equipments realized along these lines covering the frequency ranges 20 c/s–22 kc/s and 22 kc/s–10 Mc/s are considered in some detail in Section 5. In Section 6 some measurements on two- and four-poles are discussed. The influence of the tolerances of the components on the symmetry of the 3-phase generator is treated in an Appendix.

* Manuscript received 17th September, 1955. (Paper No. 335).
† Philips Research Laboratories, N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands.
U.D.C. No. 621.373.421.025.3 : 621.317.738.

2. The 3-phase R-C Oscillator

Figure 2 shows a block diagram of a symmetrical, wide-band 3-phase R-C oscillator. We have three identical valves with the mutual

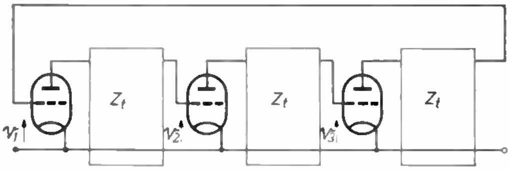


Fig. 2.—The principle of a 3-phase valve oscillator.

conductance g_m coupled by three identical transfer impedances, which can be written :

$$Z_t = \frac{R}{1 + jx}$$

where x is a function of the frequency. R is the transfer impedance when $x = 0$. The condition for oscillation is

$$\left(\frac{g_m R}{1 + jx}\right)^3 = -1$$

which gives :

$$\frac{g_m R}{1 + jx} = -1 \quad \text{or} \quad \frac{g_m R}{1 + jx} = \tfrac{1}{2} \pm j\frac{\sqrt{3}}{2}$$

The first solution cannot be used. The two other solutions give $g_m R = 2$ and $x = \pm\sqrt{3}$. We thus have two modes of oscillation. Fig. 3 shows a practical coupling circuit in an amplifier in which both modes are present. If $R_1 \ll R_2$ and $C_1 \ll C_2$ we have :

$$Z_t = \frac{R_1}{(1 + j\omega R_1 C_1)\left(1 - \dfrac{j}{R_2 C_2 \omega}\right)}$$

The circuit will oscillate on the frequencies

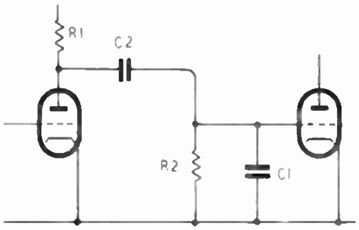


Fig. 3.—The circuit shows the two possible modes of oscillation in a 3-phase oscillator ; R1 and C1 or R2 and C2 may both give the required phase-shift.

determined by $\omega R_1 C_1 = \sqrt{3}$ and $\omega R_2 C_2 = 1/\sqrt{3}$. If the $\omega R_1 C_1$-mode is wanted, the other mode can be suppressed by making $R_2 C_2$ much smaller (5 or 10 times) in one of the stages than in the two other stages.

In the Appendix we shall consider the conditions for oscillation and the asymmetry of the three voltages in the case of a slight difference in the three coupling circuits and valves.

3. Deriving a Voltage with a Variable Phase from a 3-phase Oscillator

Let the vectors v_1, v_2 and v_3 on Fig. 4 represent the three output voltages of a 3-phase generator. To the voltage v_1 is added a voltage αv_2 (or αv_3) where $0 < \alpha < 1$, the resulting voltage being v_d. The voltage v_d may thus vary

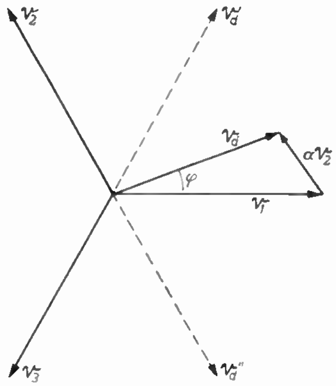


Fig. 4.—Vector diagram showing how two voltages of any phase difference can be derived from a 3-phase generator.

between v_d' and v_d'', over a range of $-60°$ to $+60°$ with respect to v_1. With respect to v_2, the voltage v_d varies between $-60°$ and $-180°$ and with respect to v_3 between $+60°$ and $+180°$. Therefore it is possible to get two voltages (v_d and v_1, v_2 or v_3) with any wanted phase difference.

Figure 5 shows a simple circuit for adding the two voltages. This circuit has the advantage that it does not cause any impedance variation on the generator terminals when α is varied. Further the output impedance is independent of α (except for the anode capacitance of the right-hand valve which will be considered below).

As can be seen from Fig. 4 the amplitude of

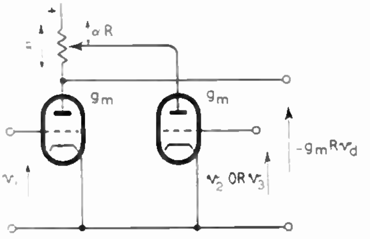


Fig. 5.—Voltage-adding circuit for obtaining any phase from a 3-phase generator.

v_d depends on α, thus also on the phase-shift, giving :

$$\frac{v_d}{v_1} = \sqrt{1 - \alpha(1-\alpha)} \simeq 1 - \tfrac{1}{2}\alpha(1-\alpha)$$

Figure 6 shows a circuit which approximately neutralizes this amplitude variation. The two potentiometers R_1 and R_2 are ganged and have the same resistance R. R_3 is a fixed resistance. When α becomes 0 or 1, R_2 becomes more loaded by R_1 and R_3, thus reducing the output voltage. If $R_3 = 0{\cdot}800R$ the amplitude of the output voltage can be kept constant within $\frac{1}{2}$ per cent.

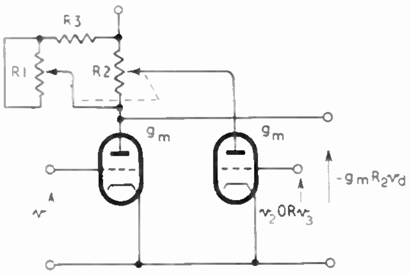


Fig. 6.—Voltage-adding circuit with output amplitude independent of the phase.

The circuit of Fig. 6 is used in the low-frequency apparatus to be described in Section 5. It is not recommended to use the circuit at higher frequencies because of stray effects ; in this case the circuit of Fig. 5 is used, and the amplitude must be corrected by an amount given by $\frac{1}{2}\alpha(1-\alpha)$.

Even if the simple circuit of Fig. 5 is used, one cannot avoid the influence of stray effects at high frequencies and the phase of v_d (see Fig. 4) will deviate from the phase read from the phase dial. This deviation can be partly compensated by giving the voltages v_1, v_2 or v_3 the same parasitic phase-shift as v_d. We thus get a circuit as shown in Fig. 7. The two inductances L are the inductances of the connections (via by-pass capacitors) between the carbon potentiometers R and the chassis.

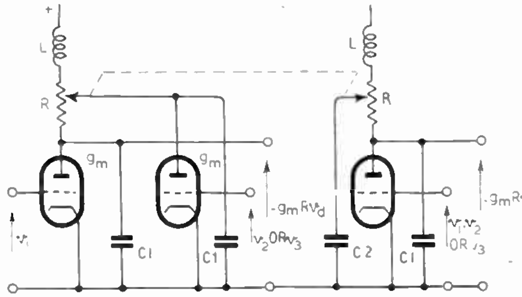


Fig. 7.—Voltage-adding circuit which compensates for parasitic phase-shift.

C_1 is the anode capacitance of the valves, C_2 is a capacitance of the same magnitude. If one writes the nodal equations of the circuit we get after solving the equations :

$$\frac{v_d}{v_{d1}} = 1 + \frac{v_2}{v_1} \times \frac{1 + \dfrac{j\omega L}{\alpha R}}{1 + j\omega\left(\dfrac{L}{R} + C_1(1-\alpha)\,.\,\alpha\,.\,R\right) - \omega^2 L C_1(1-\alpha)}$$

Taking only the first-order term of the denominator and considering it to be small compared to 1, gives :

$$\frac{v_d}{v_{d1}} = 1 + \alpha\frac{v_2}{v_1} + \frac{v_2}{v_1}\left(\frac{j\omega L}{R}(1-\alpha) - j\omega C_1 R(1-\alpha)\,\alpha^2\right)$$

The expression within the brackets is the deviation caused by L and C_1. The first term in the brackets vanishes for $\alpha = 1$, the second for $\alpha = 0$ and $\alpha = 1$. The second term has its maximum when $\alpha = \frac{2}{3}$. If $L = 50 \times 10^{-9}$ H, $R = 300\ \Omega$, $C_2 = 10^{-11}$ pF and $\omega = 2\pi.10^7$ rad, the first term gives for $\alpha = 0$ a maximum deviation of $0{\cdot}6^\circ$. For $\alpha = \frac{2}{3}$, the deviation is about $1{\cdot}8$ per cent in amplitude and 1° in phase, which can be tolerated for most practical purposes.

4. Attenuators without Phase Error

If the circuit described above has to be used for compensation measurements, we must be able to change the amplitude ratio without changing the phase difference. A resistive attenuator will introduce phase-shift at the high-frequency end of the range, if the attenuator has a reasonable impedance, while a capacitive attenuator connected to the grid of a valve will introduce phase-shift at the low-frequency end of the range because of the grid leak.

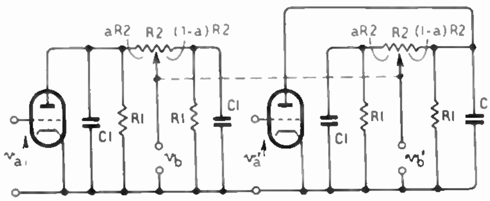


Fig. 8.—Circuit which changes the amplitude ratio between two voltages without introducing phase-shift.

If the circuit of Fig. 8 is used, the phase difference can be kept sufficiently small for our purpose. v_a and v_a' are two voltages with a certain phase difference. All capacitances C_1 have the same magnitude. The capacitance connected directly to the anodes are the valve capacitances. The R_1's are fixed resistances of the same magnitude. The R_2's are two potentiometers, the arms of which are mounted on a common shaft. Let v_b and v_b' be the voltages with the variable amplitude ratio.

From the nodal equations of the circuit of Fig. 8 one gets :

$$\frac{v_b}{v_b'} = \frac{v_a}{v_a'} \frac{R_1 + (1-a)R_2}{R_1 + aR_2} \times$$
$$\times \left(1 + j\omega C_1 R_1 R_2 \frac{1-2a}{R_1 + R_2(1+a)(1-a)}\right)$$

where a is varying from 0 to 1 when the potentiometer arm is moved. The phase deviation has its maximum value when $a = 0$ and $a = 1$. If $R_1 = 100\ \Omega$ $R_2 = 300\ \Omega$ and $C_1 = 10$ pF, the maximum deviation is 2·6° at 10 Mc/s, which is tolerable for most practical purposes.

The output terminals of the circuit of Fig. 8 will be loaded by the grid capacitance of the succeeding valves. Neither the phase difference nor the amplitude ratio of v_b and v_b' will be altered by this, because the output impedance of the attenuator is independent of a. The circuit can also be used with advantage at low frequencies, because one can increase the attenuator impedance without increasing the parasitic phase-shift. Moreover the circuit has the advantage of giving a fairly linear decibel scale when linear potentiometers are used.

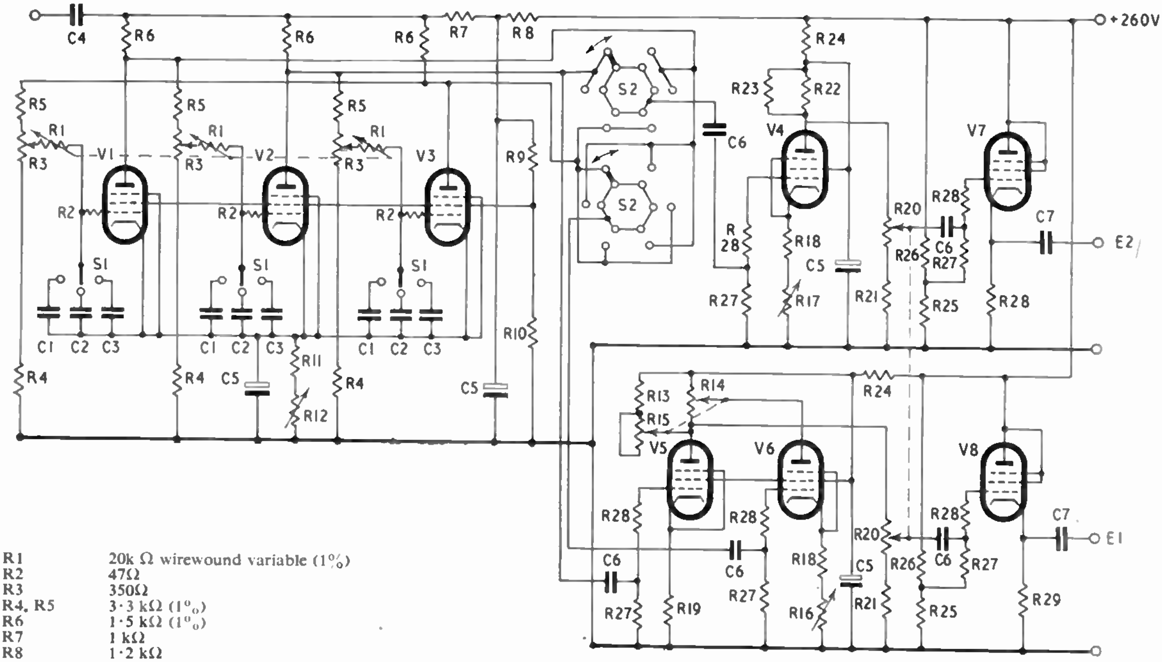
5. Practical Design of the Equipment

Two instruments have been built according to the principles mentioned above. The frequency ranges are 20 c/s—22 kc/s, and 22 kc/s—10 Mc/s.

Figure 9 shows the complete diagram of the low-frequency instrument. In the oscillator it seems attractive to make use of the phase-shift in the grid capacitors and grid leakage resistor, hence the R_2C_2-mode of Fig. 3. However, the variation of R_2 will slightly influence the amplitude of the transfer impedance of the circuit of Fig. 3, because $R_1 \ll R_2$ does not hold for all values of R_2. As a consequence, the amplitude of the oscillations depends on the magnitude of R_2, and the oscillator may even stop oscillating if R_2 has its smallest value.

The circuit ultimately adopted is shown in Fig. 9, where the R_1C_1-mode is used. The R_2C_2-mode is avoided by using a d.c.-coupling between the valves. The three ganged variable resistors R1 give a frequency range 1 : 11. By switching S1 the frequency can be raised or lowered 10 times. The amplitude of the oscillations is limited by the curvature of the valve characteristics. The amplitude of the grid voltages, which can be adjusted by means means of the variable resistor R12, is about 0·4 V. The symmetry of the 3-phase voltage can be checked by examining the voltage across the resistance R7 on an oscilloscope ; in the case of exact symmetry only the third harmonic of the oscillating frequency will be seen. In the case of asymmetry due to difference in the mutual conductances of the valves, symmetry can be obtained by adjusting the three potentiometers R3.

The two output voltages are derived from the three anode voltages of the valves V1, V2 and V3 of Fig. 9. The phase is switched from one interval to another by the switch S2. The position of the phase switch is marked with φ, $120-\varphi$, $120+\varphi$, $-120-\varphi$, $-120+\varphi$ and $-\varphi$, where φ is the reading of the continuous phase



R1	20k Ω wirewound variable (1%)
R2	47Ω
R3	350Ω
R4, R5	3·3 kΩ (1%)
R6	1·5 kΩ (1%)
R7	1 kΩ
R8	1·2 kΩ
R9	5·6 kΩ
R10	27 kΩ
R11	6·8 kΩ
R12	max. 2 kΩ
R13	4 kΩ
R14, R15	5 kΩ wirewound variable
R16, R17	100 Ω wirewound, variable
R18	220 Ω
R19	270 Ω
R20	50 kΩ wirewound variable

R21	5 kΩ
R22	5 kΩ wirewound
R23	4·7 kΩ
R24	150 Ω
R25	33 kΩ
R26	22 kΩ
R27	0·56 MΩ
R28	1 kΩ
R29	12 kΩ

C1	0·66 μF (1%)
C2	0·066 μF (1%)
C3	6600 pF (1%)
C4	10000 pF
C5	50 μF
C6	0·1 μF
C7	4 μF
V1-V3	E83F
V4-V8	EF80

Fig. 9.—Diagram of the low-frequency instrument (20 c/s—22 kc/s).

dial. The circuit of Fig. 5 is used in order to get an amplitude which is independent of φ. By means of R16 the mutual conductances of the valves V5 and V6 can be made equal.

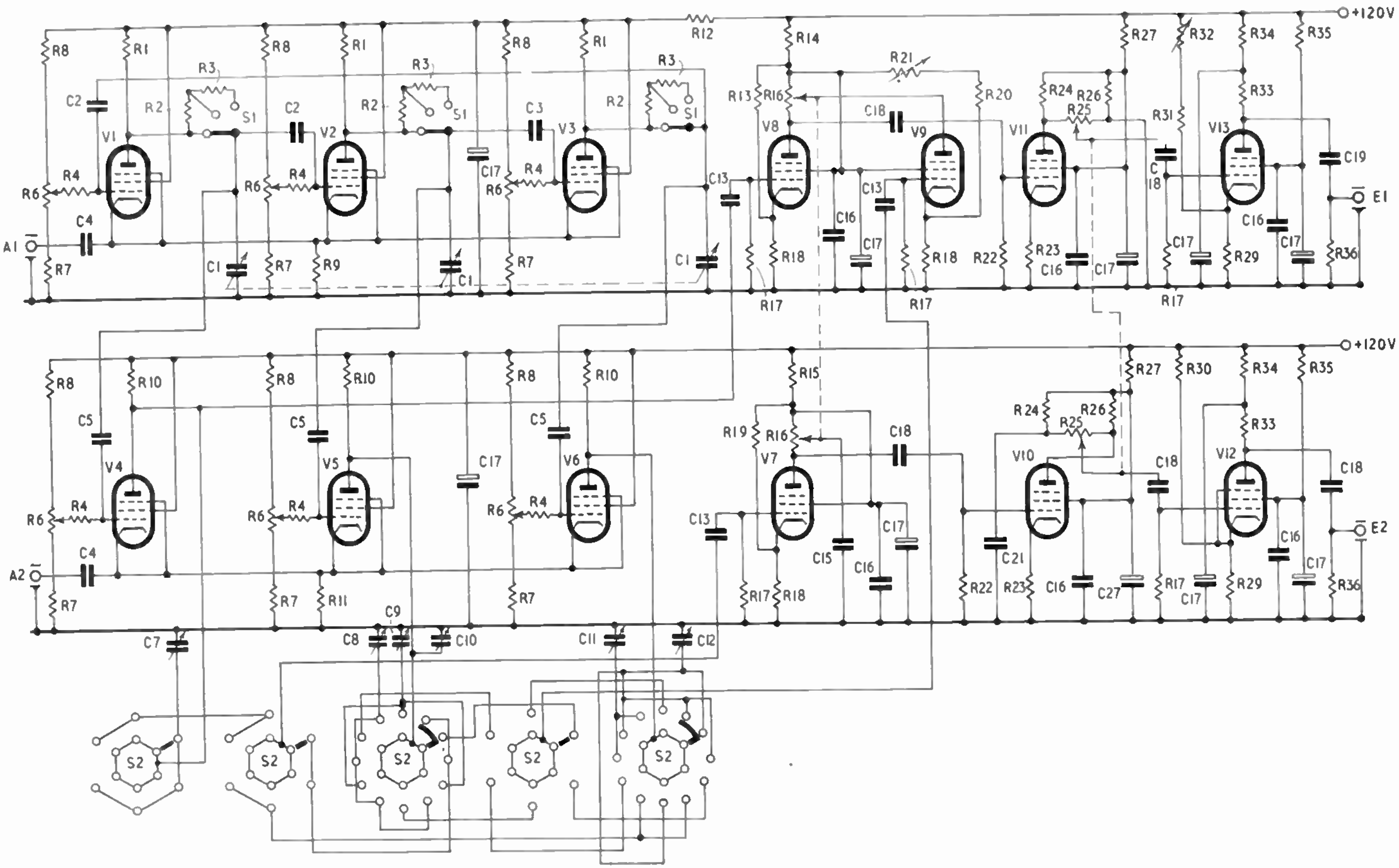
The amplitude ratio is varied by means of the circuit of Fig. 7. If the two amplitudes are not equal in the position 0 db, R17 can be varied till the amplitudes are equal. The amplitude ratio can be varied between −21 db and +21db. In the 0-db position the out-voltage is about 2 V r.m.s.

Figure 10 shows a photograph of the instrument.

The wiring diagram and a photograph of the apparatus for the high frequency range (22 kc/s —10 Mc/s) are given in Fig. 11 and 12.

In the 3-phase R-C oscillator the R_1C_1-mode of Fig. 3 is used. A triple capacitor of the type used in broadcast radio receivers is used for tuning the frequency continuously. At lower frequency ranges R2 and R3 are inserted between R1 and C1. The symmetry of the 3-phase oscillator is checked by applying an oscilloscope across the common cathode impedance R9 (terminal A1). The component of the fundamental frequency across R9 is zero in the case of symmetry. A misalignment can be readjusted by varying the grid bias of the valves by means of R6. The amplitude is limited by the curvature of the valve characteristics, the amplitude of the oscillating voltage being about 0·4 V.

The three voltages across the triple capacitor are applied to the grids of the three buffer valves V4, V5 and V6. The buffer valves have been inserted to maintain a constant oscillation frequency as well as good symmetry of the



R1	330 Ω (1%)	R13	18 kΩ	R24	100 Ω (1%)	C1	max. 450 pF (1%)	C13	10000 pF
R2	2·2 kΩ (1%)	R14	820 Ω	R25	300 Ω	C2	22000 pF	C15	8 pF
R3	22 kΩ (1%)	R15	1·5 kΩ	R26	100 Ω (1%)	C3	1000 pF	C16	0·4 µF
R4	1 MΩ	R16	300 Ω	R27	1 kΩ	C4	220 pF	C17	50 µF
R6	3·5 kΩ	R17	1 MΩ	R30	15 kΩ	C5	10000 pF	C18	10000 pF
R7	1·8 kΩ	R18	100 Ω	R31	10 kΩ	C7-C12	trimmers	C19	22000 pF
R8	3·9 kΩ	R19	12 kΩ	R32	10 kΩ				
R9	470 Ω	R20	4·7 kΩ	R33	6·8 kΩ	V1-V6	18043		
R10	100 Ω (1%)	R21	10 kΩ	R34	470 Ω	V7-V13	E83F		
R11	470 Ω	R22	0·39 MΩ	R35	12 kΩ				
R12	1 kΩ	R23	180 Ω	R36	75 Ω (1%)				

Fig. 11.—Diagram of the high-frequency instrument (22 kc/s—10 Mc/s).

three voltages when the load is varying. The symmetry of the buffer amplifier is adjusted in the same way as in the oscillator by means of the resistors R6.

After the buffer valves follows the phase-interval switch. With the simple switching circuit of the low-frequency apparatus, the different anodes of the buffer-valves would be loaded by different capacitances depending on the position of the switch, resulting in a phase error of about 4 deg. at 10 Mc/s. In order to avoid this error, the switch connects the capacitors C7—C12 (see Fig. 11) across the anodes, so that the phase remains independent of the position of the switch.

The valves V7, V8 and V9 and the two ganged potentiometers R16 provide for the continuous variation of the phase-shift. The circuit of Fig. 7 is used, in order to keep the parasitic phase-shifts in the two channels as equal as possible. Careful mounting is required in order to keep the parasitic inductance of the ganged potentiometers R16 sufficiently small. By means of R21 the mutual conductances of V8 and V9 can be made equal.

The valves V10 and V11 and the two ganged potentiometers R25 provide for the variation of the amplitude ratio. The amplitude ratio can be varied from -11 db to $+11$ db. The reading of the amplitude dial must be corrected, because the circuit of Fig. 6 is not used. The correction amounts to a maximum of 1·2 db

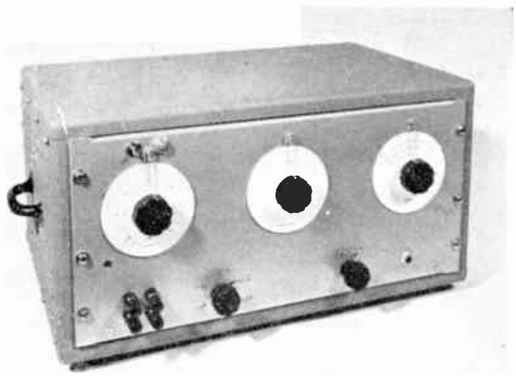


Fig. 10.—Photograph of the low-frequency instrument (20 c/s—22 kc/s). *The three dials above from left to right : amplitude dial, phase dial, frequency dial. Below, to the left the output terminals and the phase-interval switch, and, to the right, the frequency range switch and terminal for checking the symmetry of the oscillator.*

Fig. 12.—Photograph of the high-frequency apparatus. From the left to the right : terminals for the two output voltages, amplitude dial, phase dial, phase-interval switch, terminal for controlling symmetry of buffer stages, frequency range switch, terminal for controlling symmetry of 3-phase oscillator. Above frequency range switch : frequency dial.

and is printed on the phase-dial.

The arms of the two potentiometers R25 are connected to the grids of the two output valves V12 and V13. The output impedance is 75Ω. If the two output voltages are not equal when the attenuator is set at 0 db, they can be made equal by adjusting R32. The output voltages are about 15 mV when the attenuator is set at 0 db.

Experience has shown that for both apparatus in the frequency range 100 c/s—3 Mc/s the possible error is $\pm$ 0·5 db and $\pm$ 2°. From 20 c/s—100 c/s and 3 Mc/s—10 Mc/s the phase error may increase about three times while the amplitude accuracy remains nearly the same.

6. Use of the Instrument for Measurements on Two-poles and Four-poles

The two output terminals of the apparatus described above may either be considered as two constant voltage generators in series with two equal impedances or as two constant current generators parallel to two equal admittances.

The ratio between the voltages or currents of the two sources is :

$$\frac{i_1}{i_2} = \frac{E_1}{E_2} = r \, . \, e^{j\varphi}$$

where φ is the angle read from the phase dials, and $r = 10^{A/20}$, where A is the reading of the amplitude ratio in decibels.

In Table 1 block circuits are given for the measurement of two-pole and four-pole parameters. From the formulae the unknown parameters can be calculated from the readings of the dials. A two-pole can be measured either as an impedance or an admittance. It will be seen from the formulae that we are measuring the sum of the unknown impedance or admittance, and the impedance or admittance of the apparatus itself. It is therefore recommended to have $Z > Z_1$ or $Y > Y_2$, otherwise the magnitude of the unknown two-pole appears as a small difference between two large magnitudes. However, the set-up for measuring impedances requires that both terminals of the unknown impedance can be disconnected from earth. In many cases it cannot be done, then it must be measured as an admittance, possibly after Y_2 has been lowered in order to get $Y > Y_2$.

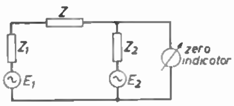
A four-pole is determined by four parameters, which establish the relations between the voltages and currents of the four-pole :

$$v_1 = a_{11} v_2 + a_{12} I_2$$
$$I_1 = a_{21} v_2 + a_{22} I_2.$$

The table shows how the four parameters can be measured.

Table 1

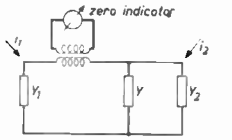
The connections and formulae for measuring two-pole and four-pole parameters



A. Measurements of an unknown impedance Z:

$$\frac{Z + Z_1}{Z_2} = r.e^{j(\varphi+\pi)}$$

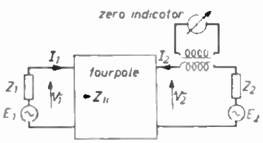
It is recommended to make $Z_1 < Z$



B. Measurement of an unknown admittance Y

$$\frac{Y_1}{Y + Y_2} = \frac{e^{-j\varphi}}{r}$$

It is recommended to make $Y_2 < Y$

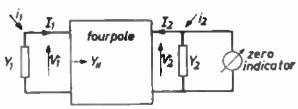


C. Measurement of a voltage ratio

$$a_{11} = \left(\frac{v_1}{v_2}\right)_{I_2=0}$$

$$a_{11} = r.e^{j\varphi} \cdot \frac{Z_{11}}{Z_1 + Z_{11}}$$

Z_{11} is the input impedance of the four-pole when open on the opposite side. It is recommended to make $Z_1 \ll Z_{11}$



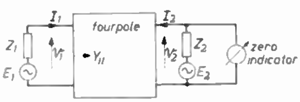
D. Measurement of a current ratio

$$a_{22} = \left(\frac{I_1}{I_2}\right)_{v_2=0}$$

$$a_{22} = r \cdot e^{j\varphi} \frac{Y_{11}}{Y_1 + Y_{11}}$$

Y_{11} is the input admittance of the four-pole when short-circuited on the opposite side. It is recommended to make

$Y_1 \ll Y_{11}$



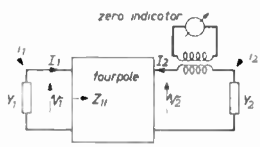
E. Measurement of a transfer impedance

$$a_{12}\left(\frac{v_1}{I_2}\right)_{v_2=0}$$

$$a_{12} = Z_2 r \cdot e^{j\varphi} \frac{1}{Z_1 Y_{11} + 1}$$

Y_{11} is the input admittance of the four-pole when short-circuited on the opposite side. It is recommended to make

$Z_1 Y_{11} \ll 1.$



F. Measurement of a transfer admittance

$$a_{21} = \left(\frac{v_2}{I_1}\right)_{I_2=0}$$

$$a_{21} = Y_2 r \cdot e^{j\varphi} \frac{1}{Y_1 Z_{11} + 1}$$

Z_{11} is the input admittance of the four-pole when short-circuited on the opposite side. It is recommended to make

$Y_1 Z_{11} \ll 1.$

7. Appendix: Influence of a limited asymmetry on the performance of a 3-phase RC oscillator

Assume that the three valves and the three networks of Fig. 2 are not identical. The mutual conductances are g_{m1}, g_{m2} and g_{m3} while the three frequency parameters have the values x_1, x_2 and x_3. Then we have:

$$v_2 = -\frac{g_{m1} R}{1+jx_1} v_1 \quad \text{.................... (1a)}$$

$$v_3 = -\frac{g_{m2} R}{1+jx_2} v_2 \quad \text{.................. (1b)}$$

$$v_1 = -\frac{g_{m3} R}{1+jx_3} v_3 \quad \text{.................. (1c)}$$

The oscillation condition is then:

$$\frac{R^3 g_{m1} \cdot g_{m2} \cdot g_{m3}}{(1+jx_1)(1+jx_2)(1+jx_3)} = -1$$

We now assume the g_m's and x's to be nearly equal and we introduce:

$$x_1 = \sqrt{3}(1+\varepsilon_1)$$
$$x_2 = \sqrt{3}(1+\varepsilon_2)$$
$$x_3 = \sqrt{3}(1+\varepsilon_3) \quad \text{.......... (2)}$$

and:

$$g_{m1} R = 2(1+\triangle_1)$$
$$g_{m2} R = 2(1+\triangle_2)$$
$$g_{m3} R = 2(1+\triangle_3) \quad \text{...... (3)}$$

where all ε's and $\triangle$'s are small compared to 1. The condition for oscillation is then:

$$8(1+\triangle_1)(1+\triangle_2)(1+\triangle_3) = -(1+j\sqrt{3})^3 \left(1+\frac{j\sqrt{3}\varepsilon_1}{1+j\sqrt{3}}\right)\left(1+\frac{j\sqrt{3}\varepsilon_2}{1+j\sqrt{3}}\right)\left(1+\frac{j\sqrt{3}\varepsilon_3}{1+j\sqrt{3}}\right)$$

Taking only first order terms we get:

$$\triangle_1+\triangle_2+\triangle_3 = \tfrac{1}{4}(3+j\sqrt{3})(\varepsilon_1+\varepsilon_2+\varepsilon_3)$$

which gives:

$$\varepsilon_1+\varepsilon_2+\varepsilon_3 = 0 \quad \text{................ (4a)}$$

and $$\triangle_1+\triangle_2+\triangle_3 = 0 \quad \text{................ (4b)}$$

We now introduce (4a) and (4b) into (1a) and (1b):

$$v_2 = (-\tfrac{1}{2}+j\tfrac{1}{2}\sqrt{3})(1+\triangle_1-\tfrac{3}{4}\varepsilon_1-j\tfrac{1}{4}\sqrt{3}\,\varepsilon_1)v_1 \quad \text{.... (5a)}$$

$$v_3 = (-\tfrac{1}{2}-j\tfrac{1}{2}\sqrt{3})(1-\triangle_3+\tfrac{3}{4}\varepsilon_3+j\tfrac{1}{4}\sqrt{3}\,\varepsilon_3)v_1 \quad \text{.... (5b)}$$

The $\triangle$'s are adjusted (by adjusting the transconductances of the valves) till we have $v_1+v_2+v_3=0$. Making use of the conditions (4a) and (4b) we then get:

$$\triangle_1 = \tfrac{1}{2}(\varepsilon_2-\varepsilon_1),\ \triangle_2 = \tfrac{1}{2}(\varepsilon_3-\varepsilon_2),\ \triangle_3 = \tfrac{1}{2}(\varepsilon_1-\varepsilon_3).$$

Introducing $\triangle_1$ into (5a) gives:

$$v_2 = (-\tfrac{1}{2}+j\tfrac{1}{2}\sqrt{3})(1+\tfrac{1}{2}\varepsilon_2-5/4\,\varepsilon_1-j\tfrac{1}{4}\sqrt{3}\,\varepsilon_1)v_1 \quad \text{.... (6)}$$

R and C, which determine the frequency, may both deviate by 1 per cent from their specified value. The product $R.C$ can thus deviate 2 per cent from the specified value. The ε's of (4a) are equal to the deviation of the individual $R.C$-products from the mean value of the three $R.C$-products. The difference between the maximum and minimum value of the ε's cannot exceed 4 per cent. The worst combination one can imagine for the ε is: $\varepsilon_1 = -8/3$ per cent, $\varepsilon_2 = 4/3$ per cent and $\varepsilon_3 = 4/3$ per cent. In this case (6) gives an amplitude deviation of 4 per cent and a phase deviation of 0·011 radian or 0·7 deg.

APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting held on 1st December, 1955, as follows:—30 proposals for direct election to Graduateship or higher grade of membership, and 30 proposals for transfer to Graduateship or higher grade of membership. In addition, 90 applications for Studentship were considered. This list also contains the names of four applicants who have subsequently agreed to accept lower grades than those for which they originally applied.

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

Transfer from Associate Member to Member

LOTT, Alan Edwin. *St. Albans.*

Direct Election to Associate Member

COOPER, George. B.Sc. *Farnborough, Hants.*
ELLIS, Edwin Jack. *Reading.*
JAQUEMET, Albert Edward, O.B.E. *Hemel Hempstead.*
LLOYD, Wilfred Edwin. B.Sc. *Wigan.*
RAMANATHAN, A. R., B.Eng., M.Sc. *Bombay.**
SAJID HASAN, B.Sc., M.Sc. *Karachi.*

Transfer from Associate to Associate Member

BARRY, Dennis George Coode. *Shilvinghampton.*
CASPERD, Stanley George. *Crowborough.*
GOODSMAN, Ronald Felix. *Trinidad.*
REID, Flt. Lt. David Atholl, R.C.A.F. *Ottawa.*

Transfer from Graduate to Associate Member

PEART, Wg. Cdr. Albert John, R.A.F. *Doncaster.*
TAW CHENG HOCK. *Singapore.*

Transfer from Student to Associate Member

PANDHARKAR, Neelkanth Gopal, B.Sc. *Mhow.*

Direct Election to Associate

BRIAN, Jack. *Cove. Hants.*
LEE, Major John Kenneth Vigers, R.Sigs. *M.E.A.F.* 19.
MACGILLIVRAY, Ronald Weston. *Liverpool.*
SARMA, Lieut. D. Parameswara Prasad, M.Sc., E.M.E. *New Delhi.*
SEED, Thomas James, B.Sc. *Christchurch, New Zealand.*
VAUGHAN, Harold James. *Newcastle-on-Tyne.*

Direct Election to Graduate

APPLEYARD, Albert Henry. *Ilford.*
CHAN YANG PUN. Bletchley.
CLARKE, Peter. *Acton.*
CRANSTON, John Alexander. *Kenton.*
CROSS, Michael Hubert. *Havant.*
CROWTHER, Geoffrey, B.Sc. *West Wickham.*
HOGGETT, George James. *Riverhead.*
JENKIN, Leonard Roy, B.Sc.(Hons.). *Exeter.*
LLOYD, Raymond Michael. *Nelson.*
PEFFERS, Donald James. *Ruislip.*
PRASAD RAO, G. S. *Jatni.*
WITHERS, William Christopher Robin. *Hampton Hill.*

Transfer from Associate to Graduate

SMITH, John Frederick. *Otford.*

Transfer from Student to Graduate

AKINDELE, Theophilus Olu. *Birmingham.*
BHARADWAJ, Shiv Kumar. B.Sc. *Delhi.*
CHRISTENSEN, Svend Aage. *Paris.*
CLARKE, Roy Wellesley. *Bournemouth.*
COX, John Edward. *Liverpool.*
GOKHALE, Narayan Ramchandra, M.Sc. *Bombay.*
GURBAX SINGH, B.A. *Jullundur.*
HARCHARAN SINGH. *Mhow.*
HOWICK, Douglas William. *Chelmsford.*
LI YUAN-LU. *London, W.2.*
MCARTHUR, Captain James, R.E.M.E. *Arborfield.*
MAHER, Stephen. *Chorley.*
SMITH, Richard. *Hitchin.*

STUDENTSHIP REGISTRATIONS

AHUJA, Puran Lal. *Kanpur.*

BENNETT, Peter Allen. *Sheffield.*
BERLING, George Paul. *Toronto.*
BHASHYAM IYENGAR, M.B. *Bangalore.*
BHAT, Jayant Trimbak. B.Sc. *Poona.*
BHAT, K. Ananda. *Bombay.**
BHATTI, Mohammad Bashir. *Qattar.**
BHUVARAGAVAN, V. *Madras.*
BINKS, John Kenneth. *Coventry.*
BOND, Norman Harry. *Northampton.*
BOSE, Shib Shekhar. *London.*
BRITTAIN-SMITH, Frederick James A. *London.*

CACHIA, Saviour. *Malta G.C.*
CERESA, Anthony. *Hayes, Middlesex.*
CHANNING, Ronald Francis. *Hampstead.*
CHAPSON, Ernest. *London.*
CHATTOPADHYAY, Anil Baran. *Agra.*
CROMWELL, Richard Arthur. *Tewkesbury.*

DAMLE, Ganesh Shridhar. B.Sc. *Bombay.*
DEB, Sida Pada. *Calcutta.*
DE SOUZA, Ignatius Anthony. *Bombay.*
DEV, Abinash Chandra. *Arborfield.*

EDWARDS, William Craig. *East Ham.*

FIRLOTTE, Joseph Leander. *Greenwood, Nova Scotia.*
FRAMPTON, Peter Guy. *B.A.P.O.* I.
FRENCH, William Robert. *Nottingham.*

GANESAN, Panchanadan. *Tiruchirapalli.*
GRAMOPADHYE, Balkrishna Dhondo, B.Sc. *Poona.*
GUPTE, Sharadchandra Keshavrao, B.Sc. *Baroda.*

HENSMAN, Roland Dharmaprabhu. *Ceylon.*
HOBBS, Norman William. *Papakura, New Zealand.*
HOGG, Barrie James. *Middlesbrough.*
HOOGHAN, Naramolaksingh Ransingh, B.A. *Bombay.*

ISLAM, Nazrul. *Lahore.*

KHADILKAR, Narayan Shankar. *Bombay.*
KIRO, Daniel. *Bihar.*
KOCHIKAR, Govind Sitaram. *Bombay.*
KRISHNA MOORTHY, A. S., B.Sc. *Bangalore.*
KRISNAMOORTHY, R. *Madras.*
KRISHNA MURTHY, Srinivas. *Jamnagar.*

LANGSTONE, Norman Edward. *Evesham.*
LIGGITT, Robert. *Billingham-on-Tees.*

MADAN, Rusi Sorabji, B.Sc. *Bombay.*
MARINOS, Stylianos. *Athens.**
MITTAL, Rajesh Chandra. *Bombay.*

NAIDU, D. S. Jithachandra, B.E. *Bangalore.*
NARAYANAN, S. R., B.Sc. *Bangalore.*
NATARAJAN, Krishnamurthy. *Madras.*
NG KENG HOCK. *Malacca.*

ORSMOND, Levinus. *Johannesburg.*

PAL, Renendra Nath. *Bangalore.*
PANCHAPIKESAN, C. *Madras.*
PARAMESWARAN, Nambudiri, K. S. *Madras.*
PASHA, Syed Akhter. *Bombay.*
PRASAD, C. Narasimha, B.E. *Nellore.*
PRITTAM SINGH, Channa. M.Sc. *Jabalpur.*
PROUD, Patrick Hamilton Godfrey. *Dublin.*

RACHAVARAO, C., B.Sc. *Bezwada.*
RAMACHANDRA, Venkatesh, B.Sc. *Kolar.*
RAMACHANDRA RAO, M. N., B.Sc. *Bangalore.*

REDGEWELL, Ronald George. *Streatham.*
ROSSI, Carlo Enrico. *Cambridge.*
RUPRAI, Balwant Singh. *Jullundur.*

SARVOTTAM VARMA. *Agra.*
SAUNDERS, Michael William. *North Cheam.*
SEBASTIAN, Chackupurkal Joseph, B.Sc. *Changanacherry.*
SHAMSHER SINGH, Jawahar. *Trimulgherry.*
SHARMA, Dharam Vir. *Trimulgherry.*
SHARMA, O. P., B.Sc. *Ambala.*
SHAUKAT ALI KHAN, B.Sc., M.Sc. *Hyderabad, Pakistan.*
SHILLING, Albert George. *Gillingham.*
SHINDE, Mahadeo Baban. *Bangalore.*
SHINDE, Yeshwantrao R., B.Sc. *Kolhapur.*
SHUM, Yau Sang. *London.*
SIDDIQI, Tausif Ahmed. *Lahore.*
SOWRIRAJAN, N. R. *Coimbatore.*
SPRATT, John Alfred Henry. *Southend-on-Sea.*
SUKUMARAN, C. K., B.Sc. *Perambavoor.*
SUNDARARAJAN, M.A., B.Sc., B.E. *Bangalore.*

TATACHRI, Rayadrug Sundararajan. B.Sc. *Madras.*
THOMAS, Edison Symonds, B.Sc. *Bangalore.*
THORNTON, Baron Arthur. *Manchester.*
TOMKINSON, Robert Christopher Hayden. *Whitley Bay.*

UPENDRA, Dattatreya Bhardvaj, B.Sc. *Bangalore.*

VASUDEVA MURTHY, B. R. *Bangalore*
VENUGOPAL, Virinchipuram Ramanathan, B.Sc. *Anantapur.*

YEONG KUM TIEN. *Singapore.*
YEOW, Charles Hock Ann. *Kuala Lumpur.*

* Reinstatement.

DISC-SEAL CIRCUIT TECHNIQUES

Part 1 — Microwave Disc-Seal Amplifiers *

by

John Swift, B.Sc.†

SUMMARY

In the first part of this paper the disc-seal valve and the basic amplifier circuit are introduced. Various aspects of valve and amplifier operations are then discussed and the theory of resonators is considered at length.

1. Disc-Seal Valves

The upper frequency limit of conventional valves is restricted by a number of factors including (*a*) impedance of the valve leads (*b*) transit time of the electrons between electrodes and (*c*) losses by radiation from the valve structure and connecting leads. The disc-seal valve[1] is the logical development of the conventional triode (or tetrode) to adapt it to operation at very high frequencies. In this class of valve, the electrodes are brought out of the vacuum envelope through disc-seals (metal to glass or ceramic), which form a natural termination for microwave resonators. Thus lead inductance and radiation losses are greatly reduced. To minimize the serious effects of transit time (see Section 7 and Ref. 2, p. 487, Ref. 3, p. 45) the interelectrode spacings are made extremely small. For example, the 2C40 lighthouse valve has a cathode to grid spacing of about 0·1 mm and the distance from grid to anode is about 0·3 mm.

The practical frequency range of disc-seal valves is from about 400 Mc/s to over 4,000 Mc/s while experimental types have been operated at well over 10,000 Mc/s.

2. The Common-Grid Circuit

A microwave disc-seal amplifier is basically the same as a tuned low-frequency amplifier. It consists of input and output resonators coupled by an electron beam, the additional r.f. energy in the output resonator coming ultimately from the d.c. power supply.

Microwave triodes, whether used as low level (signal) amplifiers or as power amplifiers are generally used in a common or " grounded " grid circuit.[2, 4, 5, 6, 9] (See also Ref. 7, p. 504, Ref. 8, p. 146.) In this type of circuit, shown in Figs. 1 (*a*) and (*b*) and 2, the grid separates the input (grid-cathode) resonator from the output (anode-grid) resonator, the only feedback coupling being via the small anode-cathode valve capacitance. Neutralization is therefore seldom needed and further, this type of circuit presents a logical termination for disc-seal triodes in which the grid is the centre disc.

Mechanical forms other than the one shown in Figs. 1 and 2 are possible. For example, in amplifiers using light-house valves where the positions of anode and cathode seals are reversed, the output resonator is inside the input line.

The input power is coupled to the grid-cathode line by means of a loop, direct connection or a probe (as shown in Fig. 1) and similar means are used for the output coupling. The d.c. connections to the valve anode and cathode are isolated from the rest of the circuit by r.f. by-pass elements and the amplifier is usually tuned by some form of movable bridge in each of the two resonators.

3. Microwave Resonators

As resonators are an essential part of microwave circuits, a knowledge of their properties is vital to an understanding of the operation of disc-seal amplifiers and oscillators.

Above about 400 Mc/s, parallel lumped-circuit resonators cease to be practical due mainly to large losses and diminishing physical size. Instead, butterfly circuits, coaxial lines, radial cavities and waveguide elements are used as resonators. (See Ref. 7, p. 460, Ref. 10,

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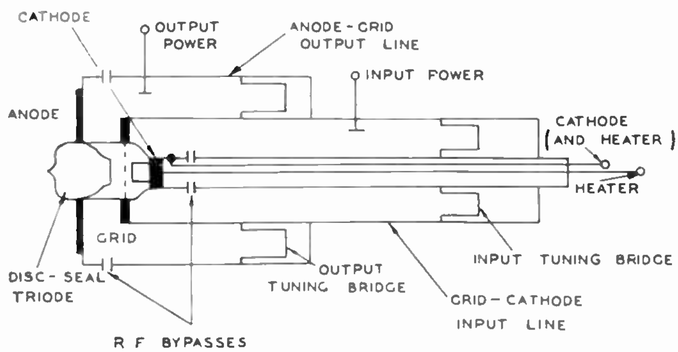
† Standard Telephones & Cables Pty. Ltd., Liverpool, N.S.W.

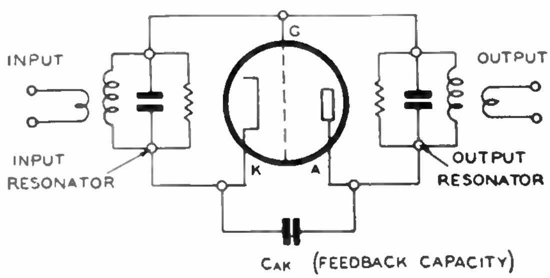
U.D.C. No. 621.375.029.6.

p. 339, Vol. 1, Ref. 10, p. 878, Vol. 2 and Ref. 11, p. 613).

Because coaxial line resonators are usually (but not exclusively) used in disc-seal circuits between about 400 and 4000 Mc/s only these will



(*a*)



(*b*)

Fig. 1.—(a) Common-grid coaxial amplifier. (b) Equivalent lumped circuit amplifier (connections omitted).

be discussed in this section. Other types of resonators are mentioned later.

3.1. *Simple Coaxial Resonator*

Consider a lossless section of coaxial line open at one end (AG) and closed at the other. (Fig. 3). The input impedance (Z_i) looking into terminals AG depends for a given frequency f and ratio b/a on the line length l.

$$Z_i = jZ_0 \tan (2\pi\, l/\lambda),$$

where λ is the wavelength at the frequency f and Z_0 is called the characteristic impedance of the line. For an air-filled coaxial line Z_0 is given by $Z_0 = 138 \log_{10} b/a$. The input impedance Z_i becomes infinite when $l = (2n+1)\lambda/4$ where $n = 0$, 1, 2 etc., and, viewed at terminals AG, the distributed line appears similar to a parallel LC lumped circuit at resonance. The shortest resonant length ($l_0 = \frac{1}{4}\lambda$, $n = 0$) is called the $\frac{1}{4}\lambda$ mode, but in contrast to the lumped circuit case, resonance will occur at an infinite number of higher frequencies corresponding to the modes $l_0 = 3\lambda_1/4$, $5\lambda_2/4$ etc.

3.2. *The Output (Anode-Grid) Resonator*

Consider now a practical resonator such as that shown between anode and grid in Fig. 1*a* and redrawn in Fig. 4.

In this case the line is not terminated by an open circuit at AG, but by the anode-grid valve capacitance C and stray circuit capacitance. The resistances shown across terminals AG and representing the external load R_L and circuit losses R_i will be ignored for the present.

For resonance to occur the total susceptance B across AG must be zero (i.e., the impedance infinite). Thus the susceptance of the capacitance, B_c, must be equal and opposite to B_l, the susceptance of the short-circuited co-axial line of length l.

Thus for resonance $B_c + B_l = 0$

$$j\omega C - j/Z_0 \tan (2\pi\, l/\lambda) = 0$$

$$\text{or} \tan (2\pi\, l/\lambda) = 1/\omega C Z_0$$

where $\omega = 2\pi f$.

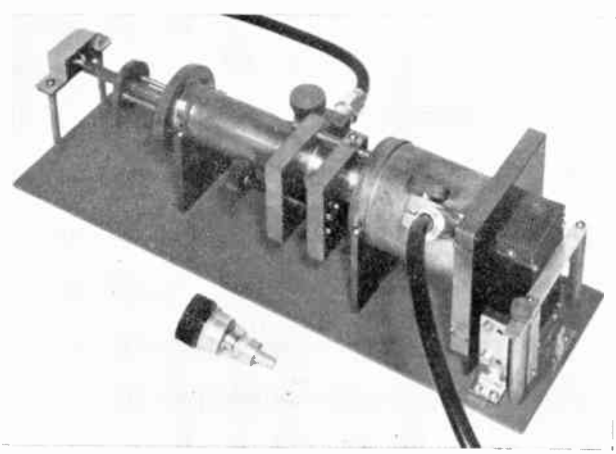
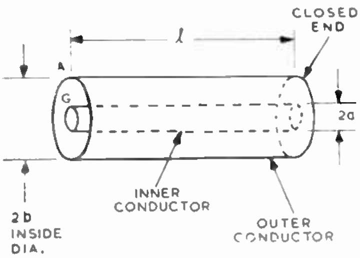


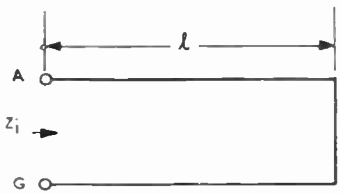
Fig. 2.—1000 Mc/s 2C39 amplifier.

The shortest resonant length l is now less than $\frac{1}{4}\lambda$ due to the foreshortening effect of C. For example, if $C = 2$ pF, $Z_0 = 30$ ohms and $f = 1000$ Mc/s ($\lambda = 30$ cm), $l = 5 \cdot 8$ cm. whereas $\frac{1}{4}\lambda = 7 \cdot 5$ cm.

If no losses were present, the distributed resonator would behave in a similar manner to



(a)



(b)

Fig. 3.—(*a*) *Section of coaxial line.*
(*b*) *Equivalent of* (*a*) *represented for convenience as a parallel line.*

a lossless, lumped circuit resonator. At instants of peak voltage along the line, all the energy is stored in the electric field while at moments of peak current, the magnetic field stores the energy. (Ref. 11, p. 622). Once started, this interchange of energy between the fields would continue indefinitely but in practical resonators losses are always present and in addition power is usually coupled out to an external load. The resultant reduction in stored circuit energy is compensated for by the valve which in turn receives the energy from the d.c. power supply.

If no external load R_L is connected, the only resistive loading present across the valve anode-grid gap is R_i. This resistance is the equivalent shunt load across the output gap due to various parallel and series losses in the resonator such as from poorly conducting walls, leakage and an incorrectly designed tuning bridge.

When the resonator is coupled to an external load to obtain useful output power, the resistance R_L is introduced and for convenience considered to be located across AG.

The amplifier thus has, in effect, two loads, one representing useful loading R_L and the other due to circuit losses R_i. For efficient amplifier operation it is evident that the power lost in R_i should be a minimum.

The load required by the valve (R_L and R_i in parallel) will depend on whether it is used in a low-level (signal) amplifier or in a power amplifier. (See Section 6.) In both cases the total working load is more or less fixed by the valve used and its d.c. ratings. For instance, in power amplifiers, the load is not impedance matched to the valve output impedance but chosen so that the valve will give optimum power gain without exceeding the d.c. ratings. A typical range of values for the working load (R_L and R_i in parallel) is from 5000 ohms to 10,000 ohms and under all circumstances would seldom be less than 1000 ohms. (For a table of values for power amplifiers see Ref. 10, p. 393, Vol. 1). For high circuit efficiency, then, R_i/R_L should be made as large as possible to ensure that nearly all the r.f. output power of the valve reaches the external load R_L.

A quantitative relation can easily be found between the circuit efficiency η and R_i and R_L. If E is the peak r.f. voltage across the terminals AG where R_i and R_L are located (Fig. 4), the

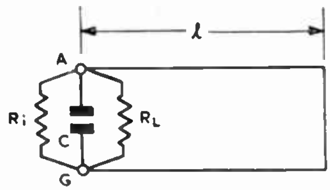


Fig. 4.—*Output* (*anode-grid*) *resonator.*

power to the load is $P_L = E^2/2R_L$ and the total power dissipated is given by

$$P_T = E^2 (R_i + R_L)/2R_i R_L$$

$$\eta = P_L/P_T = R_i/(R_i + R_L) \quad \ldots\ldots\ldots (1)$$

The factors involved in maximizing R_i and hence η are discussed in (*e*) below.

In the above discussion the valve capacitance C and the resistances R_i and R_L have been placed across a definite valve anode-grid gap, represented in Fig. 4 by the terminals AG. While such a representation greatly simplifies circuit analysis, it is usually not valid at higher frequencies where complex end effects occur, making it difficult to locate the terminals AG accurately. In this case arbitrary output gap terminals are often chosen and the resonator is replaced by an equivalent lumped circuit.[4] (See also Appendix 2.) An alternative method will be given in Part 2, Section 6.

3.3. *Q-Factor of a Resonator*

As at low frequencies, a valuable figure of merit for a microwave resonator is its Q-factor. This quantity can be measured and gives a valuable guide to circuit performance. The Q-factor is defined by

$$Q = 2\pi \times \frac{\text{energy stored in the resonator}}{\text{power dissipated per cycle}} \quad \ldots.(2)$$

If no external load R_L is present, power is dissipated entirely in circuit losses and the factor used is the unloaded Q (Q_u). When R_L is present, power is dissipated externally and in circuit losses and the factor is called the loaded Q (Q_l).

For the $\frac{1}{4}\lambda$ mode, coaxial resonator of Fig. 4, it can be shown (see Appendix 1 and Ref. 11, p. 652, Ref. 2, p. 487) that Q_u and Q_l are given by

$$Q_u = \frac{R_i}{2 Z_0} \cdot \left(\frac{\theta + \sin\theta\cos\theta}{\sin^2\theta} \right) \quad \ldots\ldots(3)$$

$$Q_l = \frac{R_i\, R_L}{2 Z_0 (R_i + R_L)} \cdot \left(\frac{\theta + \sin\theta\cos\theta}{\sin^2\theta} \right) \quad \ldots(4)$$

where θ is given by

$$\tan\theta = \tan(2\pi\, l/\lambda) = 1/\omega C\, Z_0.$$

The function in θ occurs because of the distributed nature of the voltage and current along the resonator.

3.4. *Conditions for Minimum Circuit Losses*

Considering the case where no external load R_L is present and re-arranging equation (3) above

$$R_i = \frac{2 Z_0\, Q_u \sin^2\theta}{\theta + \sin\theta\cos\theta} \quad \ldots\ldots(5)$$

where θ is given by $\tan\theta = 1/\omega C\, Z_0$.

In equation (5), the effective shunt resistance R_i is not directly related to the physical resonator losses it represents. Instead, R_i is related to the unloaded Q (Q_u) which is a function of the actual resonator losses. The reason for adopting this indirect procedure is that Q_u is a more fundamental and easily measured quantity than the physical resonator losses.

For a given line, valve and frequency, Z_0 and θ are constant and R_i is directly proportional to Q_u. Thus Q_u must be large for small circuit losses. Q_u is maximized by silver or gold plating the line conductors, by careful soldering of joints to prevent leakage and by correct design of the tuning bridges and circuit contacts to the valve electrodes.

Equation (5) will now be applied to a practical example to find an actual relation between R_i and Q_u. Consider valve type 2C39 at $f = 1000$ Mc/s, in the $\frac{1}{4}\lambda$ mode of operation and with $Z_0 = 30$ ohms. The value of C for the 2C39 (ignoring stray capacitance) is about 2 pF.

$$\tan\theta = 1/\omega C\, Z_0 = 2{\cdot}653$$

$$\theta = 69^\circ\ 21' \text{ or } 1{\cdot}2104 \text{ radians}$$

$$R_i = 2 Z_0\, Q_u \sin^2\theta/(\theta + \sin\theta\cos\theta)$$

$$= 34{\cdot}1\ Q_u$$

A typical measured value of Q_u is 1000 (although higher or lower values often occur)

$$R_i = 34{\cdot}1 \times 1000 \simeq 34{,}000 \text{ ohms.}$$

For a 2C39 power amplifier operating at 1000 Mc/s, the working load (R_i and R_L in parallel) is of the order of 5000 ohms for efficient operation. Thus, in this example, R_i is much larger than R_L and nearly all the r.f. output power of the valve reaches the useful load R_L. From equation (1), the circuit efficiency η is given by

$$\eta = R_i/(R_i + R_L)$$

where

$$R_i = 34{,}000 \text{ ohms and } R_L \simeq 6000 \text{ ohms.}$$

Hence $\eta = 34{,}000/40{,}000 = 85\%$

Consider now the case where the $\frac{3}{4}\lambda$ mode is used (i.e. one half-wavelength of line is added to the resonator). This may be necessary at high frequencies because the valve capacitance foreshortens the $\frac{1}{4}\lambda$ line to such an extent that it is not practical. The value of Q_u will not alter appreciably in changing from the $\frac{1}{4}\lambda$ to $\frac{3}{4}\lambda$ mode if the resonator losses are mainly distributed ones. This follows, because although the stored energy is much larger, the power dissipated increases in about the same ratio and therefore by equation (2), Q_u remains nearly constant.

Using equation (5) again, but with $\theta = \pi + 1{\cdot}2104$ radians, since the line length has been increased by $\frac{1}{2}\lambda$, we find

$$R_i = 11{\cdot}2\ Q_u \simeq 11{,}000 \text{ ohms}$$

Thus with higher-mode operation, the effective loss resistance across the output gap of the valve R_i approaches closer to the working load of 5000 ohms and less power reaches the useful load R_L. Using equation (1) with $R_i = 11{,}000$ ohms, $R_L \simeq 9000$ ohms

$$\eta = 11{,}000/20{,}000 = 55\%$$

If the $\frac{5}{4}\lambda$ or a higher mode is used, R_i may equal the total working load and very poor amplifier operation will result.

It has been assumed that R_i is mainly due to series, distributed resonator losses such as from poor conducting walls. If however, the physical losses are mainly parallel ones due, for example, to lossy valve glass or to an incorrectly designed tuning bridge, R_i will diminish only slowly with higher-mode operation and the circuit efficiency will be poor for all modes.

The above discussion has its counterpart in lumped *LC* parallel circuits where it is well known that for a given circuit *Q*, the value of *C* should be kept to a minimum to obtain a large value of $\sqrt{(L/C)}$ the " impedance level " parameter (Ref. 11, p. 643) and thus reduce shunt circuit losses. A coaxial line resonator may be replaced, near its resonant frequency, by an equivalent lumped circuit (Appendix 2, Ref. 4, Ref. 11, p. 649, Ref. 12, p. 437, Ref. 13) and if this is done it will be seen that the equivalent lumped *C* value is less for the $\frac{1}{4}\lambda$ than for the $\frac{3}{4}\lambda$ mode.

A useful equation relating the circuit efficiency η and the unloaded and loaded *Q* factors (Q_u and Q_l) can be derived from equations (3) and (4).

$$Q_l/Q_u = R_L/(R_i + R_L)$$

$$1 - Q_l/Q_u = R_i/(R_i + R_L) = \eta \text{ (from equation (1))}$$

$$\eta = (Q_u - Q_l)/Q_u.$$

From equation (5), it is evident that R_i also depends on the characteristic impedance Z_0 of the resonator. If the $\frac{1}{4}\lambda$ mode is used, a large value of Z_0 is helpful in reducing shunt circuit losses, but the calculation is complicated, since a change in Z_0 will also alter Q_u. It will be seen below that a high value of Z_0 is also useful in reducing the loaded circuit *Q* (Q_l) and obtaining a wide amplifier band-width.

3.5. *Loaded Q and Bandwidth*

Whereas the unloaded *Q* (Q_u) determines how much of the available r.f. valve output reaches a given external load, the loaded *Q* (Q_l) mainly governs the bandwidth of the resonator. In most amplifiers it is not only necessary to amplify the input signal but to pass a definite band of frequencies, which might be, for example, the carrier and significant sidebands of a frequency-modulated signal.

The input (grid-cathode) line is usually heavily loaded by the valve input impedance (see Sections 7, 8) and the overall amplifier bandwidth is therefore mainly determined by that of the output (anode-grid) resonator which is being discussed here.

For simplicity, circuit losses R_i will be ignored, i.e., it is assumed that Q_u is much larger than Q_l. The loaded *Q* is then a function of the load resistance R_L. (Contrast with Section 3.4 above where R_i was regarded as a function of Q_u). Ignoring R_i, equation (4) becomes

$$Q_l = R_L(\theta + \sin\theta\cos\theta)/2\,Z_0\sin^2\theta.$$

If a 2C39 valve is used in the $\frac{1}{4}\lambda$ mode at 1000 Mc/s and $Z_0 = 30$ ohms

$$\theta = 69°\,21' \text{ or } 1{\cdot}2104 \text{ radians}$$

$$Q_l = R_L/34{\cdot}1$$

For a 2C39 power amplifier a typical value of R_L is 5000 ohms

$$Q_l = 5000/34{\cdot}1 \simeq 147$$

The bandwidth Δf is defined as the frequency difference between points in the band at which the output power falls to half that at the centre (resonant) frequency. The bandwidth is related to Q_l by the expression $\Delta f = f/Q_l$. Thus in the example given $\Delta f = 1000/147 = 6{\cdot}8$ Mc/s. If now the $\frac{3}{4}\lambda$ mode is used instead of the $\frac{1}{4}\lambda$ one, θ takes a new value of $\pi + 1{\cdot}2104$ radians and

$$Q_l = R_L/11{\cdot}2 = 446 \text{ giving } \Delta f = 2{\cdot}2 \text{ Mc/s.}$$

Thus the loaded *Q* is smaller in the $\frac{1}{4}\lambda$ than in the $\frac{3}{4}\lambda$ mode and therefore for a fixed output power the $\frac{1}{4}\lambda$ mode gives a larger bandwidth. This result is often expressed in terms of a figure of merit called the gain-bandwidth product. (More precisely several such products can be used. See Ref. 4, p. 517.) The above result shows that the $\frac{1}{4}\lambda$ mode gives a larger gain-bandwidth product than the $\frac{3}{4}\lambda$ (or higher) modes. In practice an improvement factor of from 2 to 3 is obtained. This result is evident qualitatively since for a given output power to the load R_L, the $\frac{1}{4}\lambda$ mode stores less energy than the $\frac{3}{4}\lambda$ one and so, by equation (2), Q_l is less.

The value of Q_l, and hence the bandwidth, also depend on Z_0, the characteristic impedance of the line. Considering first the $\frac{1}{4}\lambda$ mode we have shown above that with $Z_0 = 30$ ohms, $Q_l = R_L/34 \cdot 1$ and $\Delta f = 6 \cdot 8$ Mc/s, when $R_L = 5000$ ohms. If Z_0 is changed to 60 ohms, θ is altered. Thus

$$\tan \theta = 1/\omega C Z_0 = 1 \cdot 326$$

$$\theta = 52° \ 59' \text{ or } 0 \cdot 9248 \text{ radians.}$$

From equation (4),

$$Q_l = R_L/54 \cdot 4 = 92$$

$$\Delta f = 10 \cdot 9 \text{ Mc/s.}$$

Thus for the $\frac{1}{4}\lambda$ mode, the loaded Q is reduced and the bandwidth increased (for constant output power) by increasing the characteristic impedance of the line. This result follows because the high impedance line stores less energy than the low impedance one for a given power to the load. For the $\frac{3}{4}\lambda$ and higher modes the effect of Z_0 on Q_l is more complex and depends on the value of θ. (See Ref. 10, p. 347, Vol. 1.)

It should be noted that a full discussion of Q_l and Q_u in the resonator would be very complicated, since so many parameters are interrelated. The above discussion has been simplified to bring out the salient points.

3.6. *Control of Resonator Bandwidth*

In 3.5 above, R_L was taken as 5000 ohms and bandwidths of about 7 to 11 Mc/s were obtained in the $\frac{1}{4}\lambda$ mode. If still wider bandwidths are required the best procedure is to couple the load more tightly to the resonator, thereby reducing R_L. The amplifier will then deliver less power (if $R_L = 5000$ ohms is the optimum value) but a controlled increase in bandwidth is possible. For example, if the coupling is such that $R_L = 1000$ ohms, Q_l becomes $29 \cdot 4$ and $\Delta f = 34$ Mc/s in the $\frac{1}{4}\lambda$ mode, for the example given in Section 3.5 with $Z_0 = 30$ ohms.

It is important to realise that the above discussion assumes that a low value of loaded Q and hence a wide bandwidth is desirable. While this is usually the case, problems may arise where a high loaded Q is desired. (See for example Part 2, Section 10.)

3.7. *Summary of the Discussion on the Output Resonator*

(1) For resonance at frequencies below about 2000 Mc/s, the line length l is related to the valve terminating capacitance C at a frequency f and wavelength λ by the expression

$$\tan (2\pi \, l/\lambda) = 1/\omega C Z_0.$$

At higher frequencies this expression is usually not valid because of complex end effects. (Part 2, Section 6.)

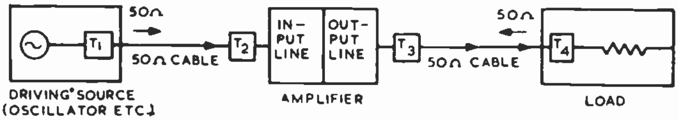


Fig. 5.—Driving source, amplifier and load.

(2) To obtain high circuit efficiency, or as much of the valve r.f. output power as possible into the external load, the effective shunt losses of the resonator should be made as small as possible compared to the working load and the $\frac{1}{4}\lambda$ mode should be used if the resonator losses are mainly distributed ones.

(3) To obtain the lowest value of loaded Q and thus the best gain-bandwidth product, the $\frac{1}{4}\lambda$ mode should be used and the resonator should have a high value of characteristic impedance.

(4) Lower values of loaded Q and hence wider bandwidths can be obtained at the expense of power gain by tighter coupling between output load and resonator than that giving best power gain.

3.8. *The Input (Grid-Cathode) Line*

The input line differs from the grid-anode output resonator discussed above in that it is usually loaded very heavily by the valve input impedance. (See Sections 7 and 8.) In practice the shunt resistance across the input can easily be less than 100 ohms whereas the loading on the output resonator is usually several thousand ohms. A full discussion of the input line is too complex to be given here and only one further point is added. The input line is not a resonator in the usual sense because unlike the output line it cannot be regarded as a lossless resonator with a reasonably small perturbation present (the load and loss resistances in the output line). The procedure involved in matching to the input line is discussed in Section 5.

4. Tuning of Resonators

The input and output lines of microwave amplifiers are normally tuned by some form of movable bridge, which varies the positions of the short circuits and hence changes the amplifier operating frequency.

A detailed discussion of tuning devices for resonators is given in Section 9 of Part 2 of this paper.

5. Coupling to Coaxial Resonators

In order to connect the input and output resonators of an amplifier to the driving source and output load, coupling devices are required. These are essentially impedance transformers and at microwave frequencies are usually direct junctions, or untuned loops and probes. As the theory of these is complex only the general principles will be discussed here. (See Ref. 11, p. 654, Ref. 7, p. 513.)

When an amplifier is set up with the driving source and output load connected, the arrangement is usually as represented in Fig. 5.

It is assumed for convenience that the connecting cable has a characteristic impedance of 50 ohms and that both the source and load are matched to the cable by the transformers T1 and T4. The input cable connects to the amplifier input line via the coupling T2 and T3 connects the output resonator to the load. The properties of T2 and T3 should be such that the available power from the source reaches the valve input with negligible reflection and that the external load reflects back on the grid-anode output gap the optimum operating impedance. The coupling devices of interest here are T2 and T3 and as the requirements are somewhat different in the input and output lines, the cases are discussed separately.

5.1. *The Output Coupling*

The output (anode-grid) resonator is coupled via T3 to the 50 ohm connecting cable and thence to the 50 ohm load. (More precisely a load which has been matched to the end of the cable by T4.) The output arrangement is shown in Fig. 6. Circuit losses R_l are ignored.

The output coupling is shown at some convenient terminals XX along the line. The input impedance to the connecting cable will be 50 ohms since its other end is matched to the load, so that T3 must transform 50 ohms to a new impedance across XX which when viewed from the valve output gap (AG) has a value of R_L (Fig. 6 (*b*)). The load R_L has the same significance as in Section 3, but there the means of adjusting it to the correct value were not discussed.

The value of R_L required by the valve will determine the impedance transformation of T3 and the type of coupling used will decide the location of the connecting terminals XX along the line. For example, assume an electrostatic probe is used (see 5.3) in a $\frac{1}{4}\lambda$ line and a value of $R_L = 5000$ ohms is desired. The probe should be placed in a strong electric field so that for the $\frac{1}{4}\lambda$ mode, terminals XX would be as close to the valve gap (AG) as possible and the impedance transformation of T3 required is from 50 ohms to 5000 ohms (approx.).

It is a property of the output line (as distinct from the input line) that at any terminals XX along the resonator, the input impedance (seen looking into XX) is to a very close approximation purely resistive. Thus in the above example, as XX is moved from position AG to the end short circuit, the impedance seen looking into terminals XX changes from $(5000 + 0j)$ ohms to $(0 + 0j)$ ohms (at least very closely). It can

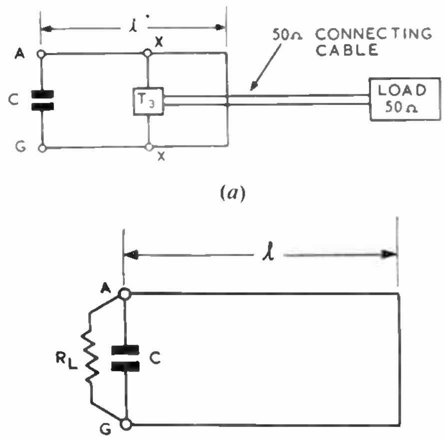


Fig. 6 (a).—Output line to load coupling (circuit losses ignored). (b) Equivalent circuit to (a).

easily be ascertained that at any terminals XX of a lossless resonator, the input impedance at XX is always infinite (i.e., when resonance occurs, the input terminals are invariant) and for a resonator with relatively light loading (such as the output line), this condition still holds true except that the input impedance is not infinite but a finite resistive value. Even with a loading of 1000 ohms the impedance at any terminals XX is very nearly a pure resistance. Thus the output coupling device has only to transform the 50 ohm output loading to another resistance value.

The discussion above has been simplified, since other factors such as coupling reactance (Ref. 11, p. 646) and the case where the output load is not matched to the connecting cable are not considered.

5.2. *Untuned Coupling Loops*

One common type of coupling device is a small, untuned loop which is placed at a point of strong magnetic field or high current in a coaxial line resonator. (Fig. 7). Because of flux linkages with the loop, a voltage is generated

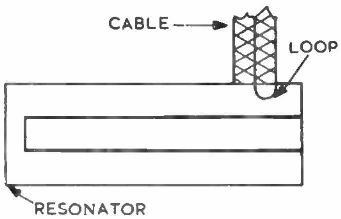


Fig. 7.—Untuned loop coupling.

across it and the device couples to the resonator energy. (Ref. 11, p. 674.) The induced voltage is proportional to the magnetic flux density, the frequency, the area of the loop, and the cosine of the angle between the direction of magnetic flux and the normal to the plane of the loop. The voltage, and hence the impedance transformation, is usually controlled by changing the lateral position or orientation of the loop. Inserting the loop into the output resonator changes the resonant frequency but this effect is usually small and can be tuned out.

5.3. *Untuned Electrostatic Probes*

An alternative to the untuned loop is the electrostatic probe which is particularly useful if the coaxial cable centre conductor must be insulated from the resonator for d.c. or low frequencies (Ref. 11, p. 682). It is used at points of strong electric field, or at high voltage points in a coaxial line resonator.

The probe shown in Fig. 8 is simply the extension of the connecting cable inner conductor with a small metal disc added at the end. To a first approximation the probe voltage generated is $E.S$ where E is the electric field intensity at the probe (assumed uniform over the probe length) and S is as shown in Fig. 8. More generally, the open circuit probe voltage is equal to $E.S'$ where S' is called the effective probe length. The value of S' depends on the probe construction and for a probe with a large terminating disc, $S' \simeq S$, the physical length. The concept of effective probe length is very useful as it applies to any microwave resonator, not only to coaxial line types.

The voltage generated across the probe is altered by varying its penetration into the resonator and thus for a given probe size, the impedance transformation depends on only one parameter.

When a probe is inserted into a resonator, the resonant frequency is altered but the line can easily be retuned to the original frequency.

5.4. *Equivalent Lumped Circuits for Loops and Probes*

It can be shown that, under certain circumstances, distributed resonators (coaxial lines, radial cavities and wave-guide elements) can be represented by equivalent lumped circuits. This is often very convenient for examining the action of coupling devices connected to resonators. (See Appendix 2, Ref. 11, p. 654, Ref. 10, p. 376, Vol. 1.)

5.5. *Wide-Band Output Coupling*

Although loops and probes are quite flexible and will operate satisfactorily even in relatively weak magnetic and electric fields respectively, trouble is often encountered in amplifiers tunable over a wide frequency range. For example, a probe placed at a fixed point along

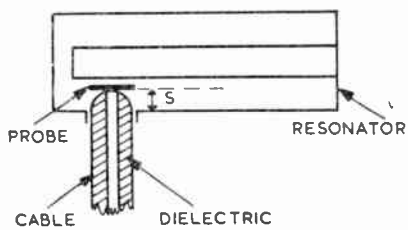


Fig. 8.—Untuned probe coupling.

the resonator may be at a voltage node (and hence zero electric field) at some frequency in the band.

One method of overcoming this problem is to use a loop placed in the face of the moving shorting bridge where the current is always large and the magnetic field therefore strong. This, however, is not always a convenient method due to mechanical difficulties and because the capacitance between the loop and resonator conductors may upset the loop operation. A better method is to use a combined loop–probe system (Ref. 10, p. 387, Vol. 1) which operates well over a wide frequency band. In particular, if the $\frac{1}{4}\lambda$ mode is used, an electrostatic probe placed as close to the valve as possible will be found satisfactory. A loop in the back shorting bridge can also be used if mechanically possible.

For the $\frac{3}{4}\lambda$ mode (and higher modes), a probe placed $\frac{1}{4}\lambda$ from the back short circuit may be used when a moderate frequency range is to be covered (λ being the wavelength at the centre of tuning range). As an alternative a loop placed $\frac{1}{2}\lambda$ from the shorting bridge will often be satisfactory. (See Ref. 10, p. 916, Vol. 2.) In the author's experience, probes have proved to be more flexible and easier to adjust than loops and their physical size is not critical.

5.6. *Coupling to the Amplifier Input Line*

This case is seldom discussed in text-books and is more complex than at first appears, due to the heavy damping normally present across the line at the grid-cathode gap due to beam loading (Section 7).

The connection of the source (of 50 ohms internal impedance) to the input line via the coupling device T2 is shown in Fig. 9. In general, at any pair of input terminals XX, the impedance presented is not purely resistive except at GK and at the short circuit in the case of the $\frac{1}{4}\lambda$ mode. In general too, the "resonant" length l is not given by the familiar expression $\tan(2\pi l/\lambda) = 1/\omega C Z_0$.

The input line is usually matched to the driving source impedance (here 50 ohms), since mismatching the input at frequencies above about 1000 Mc/s seldom improves the noise factor. Matching to the valve input impedance is best accomplished in much the same way as an arbitrary load is matched to a given connecting cable using a movable junction and stub. (See Ref. 11, p. 523.) In Fig. 9, l_2 is the distance between the load (R and C in parallel) and the driving source connection. Distance l_1 is the stub length and is such that the total susceptance across XX is zero and the input impedance there is a pure resistance. For instance, if looking to the right of XX the admittance is $G - jB$, then the stub length l_1 is adjusted so that the stub presents a susceptance of $0 + jB$ at XX and gives a resultant input impedance of $1/G + 0j$ ohms. If, for example, $1/G$ has a value of 150 ohms, then a probe placed at XX should transform the 50 ohm input impedance to 150 ohms so that all the available source power will reach the valve and be dissipated in R.

As the frequency is changed, the stub length l_1 must also be altered to produce a resistive input at XX and as this impedance will generally change with frequency the probe penetration must be altered to keep the correct impedance transformation. Using a probe in a fixed position relative to the valve (i.e., l_2 constant) and changing only the probe penetration and distance l_1, the author has used this method to obtain almost perfect matching from 1700 Mc/s to 2300 Mc/s.

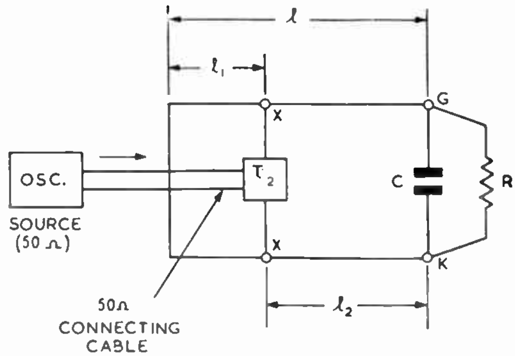


Fig. 9.—Input line matching.
$1/R$ = *valve input conductance.*
C = *grid-cathode valve capacitance (plus strays).*

At high frequencies the distance l_2 is difficult to measure since the terminals GK are not easily defined. The best procedure then is to build an initial experimental input line with a movable input probe, so that the best position l_2 can be found.

In practice the input line generally extends beyond the output line to allow a suitable input coupling to be made. (See Fig. 1.) Usually the use of higher "modes" (i.e., additions of $\frac{1}{2}\lambda$ to the line length) does not reduce the input line bandwidth to that of the output but trouble may occur with interfering modes if the $\frac{1}{4}\lambda$ mode is not used in the output line. This will be discussed in Part 2.

The use of a loop in the back shorting bridge of the input line is not generally very satisfactory since, as explained above, a large reactance is usually present across the input terminals XX in addition to the resistive component. If the loop coincided exactly with the back short circuit this difficulty would not occur, but this is not feasible in practice.

A direct junction connection (Ref. 11, pp. 654 and 672) can be used but it is not as flexible as the probe and would need to be adjustable for wide-band input matching.

6. Low Level and Power Amplifiers

Microwave disc-seal amplifiers are normally used in two distinct applications. One is as a signal amplifier where the weak input to the aerial of a microwave receiver is amplified before being passed on to the mixer and i.f. amplifier. The noise factor is normally not low enough for this application with most available disc-seal valves, but special types have been developed and used satisfactorily at frequencies as high as 4000 Mc/s. (See for example Refs. 4, 14.)

While a number of papers have been written on the theory of low-level microwave amplifiers, the operation is still not fully understood. (See Refs. 4, 9, 14, Ref. 7, p. 504, Ref. 8, p. 97.)

The second application is as a high-level amplifier, amplifying for example the output of a modulated oscillator before feeding the power to a transmitting aerial. This case is similar to the high-efficiency class-C amplifiers used at lower frequencies, but due to transit time (Section 7) and difficulty in obtaining efficient circuits (Section 3), low-frequency efficiencies are not normally attainable. Again the theory is only partially understood, but excellent accounts are given in Refs. 2 and 7.

7. Transit Time Effects

As the operating frequency of disc-seal power amplifiers is increased, it is found that the efficiency steadily falls below that attained at lower frequencies. One reason for this is the increasing problem of obtaining high circuit efficiency, but a more fundamental reason is found in the motion of the electrons within the valve. At high frequencies the time of transit of electrons between valve electrodes may become a large part of one cycle and various effects occur to cause poor amplifier performance.

For low-level amplifiers, the main electron movement is determined by d.c. valve potentials and the superimposed r.f. input signals cause only small perturbations in the movement. For power amplifiers, the large r.f. input signals greatly modify the electron movement and in a class-C amplifier many electrons leaving the cathode may be returned since the field between cathode and grid has become a retarding one during transit.

The theory of transit time is not yet completely understood but a number of references are available.[2, 7, 8, 10, 15, 16, 27, 30] The theory is too complex to be given here but some of the effects on amplifier performance are given below.

7.1. *Cathode Back-Heating*

At frequencies where transit time effects are important, electrons moving towards the grid are retarded in transit and in returning, bombard and heat the cathode, thus reducing cathode life and also reducing the effective valve current in the grid-anode space. This effect is particularly important when a large r.f. input voltage and high values of negative grid bias are used (i.e. in class-C operation). Electrons that are retarded in transit to the grid and forced to return to the cathode may be strongly accelerated by the reversed grid-cathode field. As a result they strike the cathode with far more kinetic energy than they possessed initially.

It has been claimed[2] that in a 2C39 power amplifier operating at 3000 Mc/s, the heater power could be removed without affecting the performance. Because of back-heating, valve manufacturers usually specify lower heater voltages at the higher frequencies to ensure satisfactory valve life.

7.2. *Input Loading*

The r.f. input provides most of the power in the back heating phenomenon and thereby causes an effective lowering of valve input impedance. This effect, sometimes called total emission damping[17] is partly responsible for the fact that the input line of an amplifier normally has a wider bandwidth than the output one.

7.3. *Reduction in Power Gain*

The amplifier power gain is reduced in two ways. More input power must be provided to compensate for that lost in cathode back-heating and the returned electrons reduce the effective valve current, both effects acting to reduce the power gain.

7.4. *Valve Load Impedance*

The reduction in useful valve current for the same anode r.f. voltage swing has the effect of increasing the value of optimum valve load impedance. (R_L and R_i in parallel in Section 3 above.) For good circuit efficiency the working load should be much lower than that presented by losses (R_i) so that most of the valve r.f. output reaches the external load. Transit time effects tend therefore to bring the shunt losses and the required operating load closer together with resultant poorer amplifier operation.

7.5. *Class-C Operation*

If a power amplifier is used in extreme class-C conditions (i.e., cathode current flows for only a very small part of each cycle), all the effects mentioned above occur in an extreme form and compromise performance. Yet for best electronic efficiency class-C operation would be used if no transit time effects were present (Part 2, Section 4, and Ref. 18).

Thus at frequencies where transit time is important class-B operation may give better performance than extreme class-C operation.

7.6. *Reduction of Transit Time*

While many factors may be involved in the poor performance of disc-seal valves at high frequencies, transit time is always the ultimate limitation. Since electron transit time decreases with increase of anode voltage and with decrease of electrode spacing, valve performance can be improved by raising the operating voltage or by reducing the electrode spacing.

High anode voltage however results in increased anode dissipation and a decrease in electrode spacing increases the inter-electrode capacity. If the electrode spacing and electrode areas are reduced simultaneously in order to avoid increasing capacitance the allowable plate dissipation is reduced.

The comments above suggest why disc-seal valves capable of operating at very high frequencies (3000 Mc/s and above) have low dissipation ratings and why pulsed operation gives better results than when the amplifier is used under c.w. conditions.

8. Regeneration in Amplifiers

In common-grid circuits the only coupling between resonators (apart from through the electron beam itself) is via the small anode to cathode valve capacitance and possibly through the circuit to grid flange contacts. Although this type of circuit does not usually require neutralization, regeneration or unwanted coupling of energy between resonators often causes problems in disc-seal amplifiers.

Even if regeneration is insufficient to cause actual oscillation, the tuning may become erratic and the amplifier bandwidth greatly reduced and assymetrical. The reduction in bandwidth occurs because the effect of coupling back energy to the input line is to reduce the damping on this normally heavily loaded line. This effect may be so pronounced that the input line becomes the main factor in determining the over-all amplifier bandwidth and the gain–bandwidth product of the device falls rapidly. (See Section 3.) Further it can be shown that a change in loading on the input line due to regeneration will cause detuning and a loss of input power to the amplifier.

The best method of reducing regeneration is to load the output resonator heavily, even though less output power will be obtained. This is normally no problem as the output line to load coupling is often made quite tight to ensure adequate bandwidth. (See Section 3.) The procedure given below is recommended for stopping or at least minimizing regeneration in amplifiers.

(*a*) Remove the output load and input power and tune the amplifier over its operating band. Under these conditions oscillation may occur at various frequencies in the working band or at values corresponding to lower modes. (For example if the output resonator uses the $\frac{3}{4}\lambda$ mode, a spurious response corresponding to the $\frac{1}{4}\lambda'$ mode can occur with correct input line tuning, if the regeneration is sufficient.)

(*b*) Connect the external load and increase the coupling to the output resonator until no oscillation occurs over the amplifier tuning range.

(*c*) Connect the input drive and leaving the output coupling in the position found in (*b*), tune the amplifier to the source frequency and read the output power.

(*d*) Disconnect the input drive and make sure there is no output from the amplifier. Re-connect the input power and note the amplifier output reading. If it is not much the same as before regeneration is probably occurring. In such cases the drive tends to "trigger" the amplifier, even though it will not oscillate by itself.

(*e*) Increase the output loading until consistent output powers are obtained with a given input drive.

(*f*) As a check, perform an over-all amplifier band-width test (see Section 12). When operation is normal the amplifier band-width should be reasonably symmetrical.

While neutralization of common-grid amplifiers is possible and in fact has been obtained accidentally by using incorrect feedback in oscillators, it is not practical as conditions are too difficult to control.

In some cases, the regeneration via the valve anode to cathode capacitance is actually used (and sometimes deliberately enlarged) to provide the feedback path in an oscillator. (See Part 2.)

9. Radial Cavity Amplifiers

Although coaxial line resonators are usually used in disc-seal amplifiers, another type of resonator called the radial cavity is sometimes employed. (Refs, 19, 20, 21, Ref. 22, pp. 240-282, Ref. 23, p. 137.)

One application of the radial cavity is when the $\frac{1}{4}\lambda$ mode in a coaxial resonator is too short to be practical (due to valve capacitance loading and end-effects) and band-width requirements preclude the use of higher modes. (Section 3.)

Radial cavities may be used for both input and output amplifier resonators but the usual arrangement is to use a coaxial grid-cathode input line and employ a radial cavity as the output resonator. Such an amplifier is represented in Fig. 10.

The unloaded Q (Q_u) of the radial cavity output resonator can be made very large with resultant high circuit efficiency.

The cavity can be tuned over a small frequency range using a brass screw, the resonant frequency increasing with greater screw penetration.[19] Generally, direct tuning of a radial cavity amplifier over a wide frequency range is not possible and in this case a coaxial line resonator would be preferable.

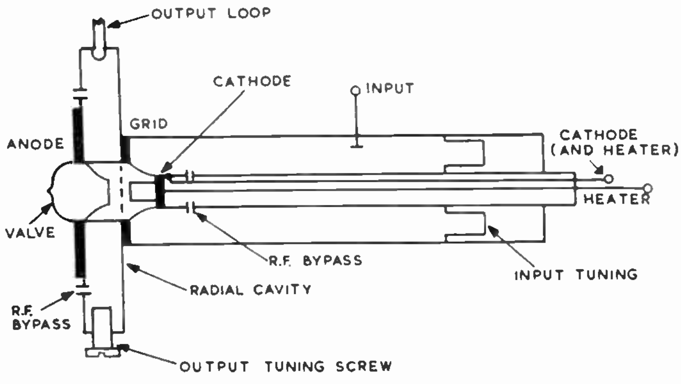


Fig. 10.—Radial cavity amplifier.

Loop coupling is used to supply power to the external load, although other methods such as an iris or a coupled low impedance coaxial line can also be used. (See Ref. 14, p. 532.)

The calculation of cavity size to give the desired resonant frequency is often difficult due to the number of re-entrant sections that occur when the valve is placed across the resonator. A reasonable approximation can be obtained however, using the graphs of Ref. 20, p. 213, or the methods of Ref. 22, p. 273.

The field pattern inside a radial cavity differs from that in a coaxial line except over the range where one type of resonator merges into the other.[21]

No theory of radial cavities is given here and the reader should consult the above references (particularly Ref. 19) for further information. Methods for finding the Q-factor of this type of resonator, are given in Ref. 11, p. 625 and Ref. 23, p. 137.

10. Waveguide Amplifiers

An alternative to the radial cavity resonator, discussed in Section 9, is the use of elements of rectangular waveguide. (See Ref. 7, p. 469, Ref. 24, Ref. 25, p. 482, Refs. 28, 29.)

It is unfortunate, however, that at higher frequencies (above about 3000 Mc/s) where waveguide resonators could conveniently couple directly to other waveguide elements, great difficulty is experienced in making the resonator operate in the desired mode. (" Mode " is used here to describe the actual field configuration. In coaxial lines the term mode usually means the number of quarter-wavelengths of line in the resonator. The two meanings are often used indiscriminately in text-books but fortunately the meaning is usually clear.)

Probably, with careful design this type of resonator could be used over a wide range of frequencies, and particularly at the high end solve many difficulties, such as losses in connecting lines, etc. For descriptions of several amplifiers using rectangular waveguide resonators the reader should consult the references given above, particularly Ref. 28.

Rectangular waveguide resonators offer an interesting alternative to coaxial lines when the latter are too short to be feasible in the $\frac{1}{4}\lambda$ mode. As explained in Section 3, the use of higher coaxial modes will greatly reduce the amplifier bandwidth. By choosing the waveguide dimensions such that the guide wavelength is much longer than the free space (operating) wavelength, a disc-seal valve can be placed in the centre of a resonator only one half-wavelength long. The bandwidth of such a resonator would be larger than that obtained from a $\frac{3}{4}\lambda$ coaxial resonator. (Ref. 3, p. 32.) The problem of spurious modes arises again, however, and these must be suppressed to obtain satisfactory operation.

11. Multiple Valve Amplifiers

A useful modification of the coaxial line circuit is the annular resonator. (See Ref. 7, p. 476 and Ref. 26.) The advantage of using this resonator in an amplifier is that it may be excited simultaneously by a number of valves placed symmetrically about the axis in the region of high electric field strength. A c.w. power output of 500 watts at 1000 Mc/s has been obtained in this type of amplifier using fourteen 2C39 triodes.

Other possibilities for multiple valve circuits are mentioned in Ref. 3, p. 74.

12. Testing Microwave Amplifiers

Three tests frequently made on microwave amplifiers are power gain, bandwidth and input matching measurements. A suitable testing arrangement is shown in the block diagram below (Figure 11).

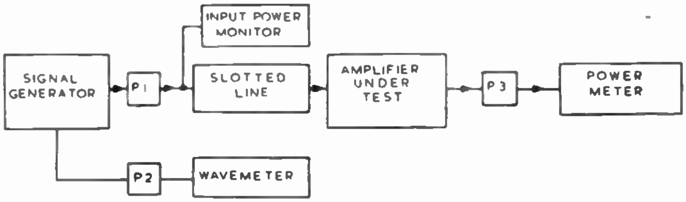


Fig. 11.—Testing arrangement for amplifiers. P1, P2 and P3 are isolating attenuators.

12.1. *Power Gain Tests*

The power gain is simply the ratio of amplifier output to input power and is usually expressed in decibels. If, when the amplifier is tuned to the desired frequency, the input and output power indicators read P_i and P_o respectively, the power gain G is given by

$$G = 10 \log_{10}(P_o/P_i) \text{ db.}$$

Naturally both power indicators should be as accurate as possble, should preferably be wide-band devices and should be capable of operating at the required power levels. A suitable input monitor is a directional coupler and a convenient output power meter is a wide-band thermistor mount and bridge together with suitable calibrated attenuators.

12.2. *Bandwidth Tests*

The amplifier is first tuned to frequency f_0 the centre of the band in use. Assume that with an input drive of P_i, the amplifier output power is P_o. The signal generator is now tuned to frequencies f_1 and f_2 either side of f_0 such that with constant input power P_i (read on the input monitor) the output power falls to $\frac{1}{2}$ P_o. The bandwidth is then $f_2 - f_1$ (assuming $f_2 > f_1$). If the input power changes with frequency or the input monitor is frequency sensitive, a correction must be applied.

If a larger bandwidth is required, the external amplifier load is coupled more tightly to the output resonator (see Section 3), the output line is retuned to f_0 and the output power P_o' (which is less than P_o) is read on the indicator. The frequencies f_1' and f_2' at which the amplifier power falls to $\frac{1}{2}$ P_o' are found as before.

A more accurate method of finding the bandwidth involves plotting a curve of the power output at various frequencies either side of the centre one.

12.3. *Input Matching Tests*

The amplifier input matching is measured with a standing-wave detector. The input matching at the centre frequency f_0 should be close to unity, if the input coupling has been designed correctly. (See Section 5.)

If a power amplifier is under test, the output resonator must be tuned to f_0 as well as the input. In the case of low-level (signal) amplifiers this is not necessary providing no regeneration is present. (See Section 8.) With the amplifier tuning left fixed, the input standing wave ratio is then measured against the frequency of the input signal at various points either side of f_0.

If the amplifier has been designed to present (for example) a 50 ohm input impedance and the signal generator is well isolated by a 50 ohm attenuator, adjustment of the input line for maximum amplifier output power should produce a good input match. If however, the signal generator is not isolated from the amplifier input, maximum amplifier output power will not necessarily correspond to matched input conditions.

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14. Appendix 1: The Q of a Coaxial Line Resonator

The Q-factor

The Q is defined by

$$Q = 2\pi \times \frac{\text{stored resonator energy}}{\text{power dissipated per cycle}} = \frac{\omega W}{P}$$

where W is the energy stored in the resonator and P is the power dissipated. To illustrate the

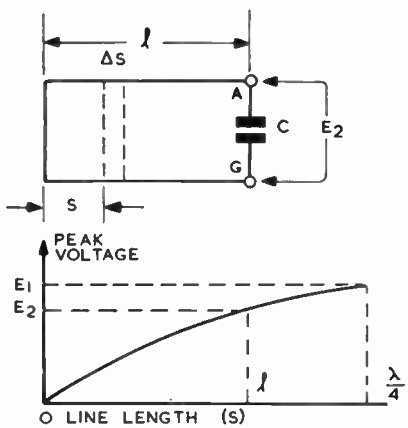

Fig. 12.—Illustrating the derivation of the Q-factor of a ¼λ mode coaxial resonator.

method used, the Q-factor of the $\frac{1}{4}\lambda$ mode coaxial resonator of Fig. 12 will be found. To do this it is necessary to evaluate W and P.

Stored Resonator Energy (W)

Because of the 90-deg. phase relation between peak current and voltage along the line, all the energy is stored in the magnetic field at instants of peak current and in the electric field at instants of peak voltage. In the present case it is more convenient to calculate the energy stored in the electric field which consists of two parts W_1 and W_2. W_1 is the energy stored in the line and W_2 is that stored in the terminating capacitance C.

Energy stored in the line (W_1):

For a small element ΔS of a line of capacitance per unit length C_0

$$\Delta W_1 = \tfrac{1}{2}\,(C_0\,\Delta S)\,(E_1 \sin\beta S)^2$$

where $\beta = 2\pi/\lambda$ and E_1 is the peak voltage that would exist across the terminals AG, if $l = \frac{1}{4}\lambda$ and C were not present. (With C present, the actual terminal voltage is E_2 which is less than E_1 and the two are related by $E_2 = E_1 \sin\beta l$).

$$\Delta W_1 = \frac{C_0 E_1^2}{2\beta}\,.\,\sin^2(\beta S)\,.\,\Delta(\beta S)$$

$$W_1 = \frac{C_0 E_1^2}{2\beta}\int_0^{\beta l}\sin^2(\beta S)\,d(\beta S)$$

$$= \frac{C_0 E_1^2}{4\beta} \times (\beta l - \sin\beta l\cos\beta l)$$

Now $Z_0 = \sqrt{L_0/C_0}$ and $\gamma_0 = 1/\sqrt{L_0 C_0}$

where γ_0 is the propagation velocity in an air filled line, Z_0 is the line characteristic impedance and L_0 is the line inductance per unit length.

$$C_0 = 1/\gamma_0 Z_0 = 1/\lambda f Z_0 = \beta/\omega Z_0$$

Hence $W_1 = \dfrac{E_1^2}{4\omega Z_0}\cdot(\beta l - \sin\beta l\cos\beta l)$

The actual peak voltage across the terminals AG is E_2 and is related to E_1 by $E_2 = E_1 \sin\beta l$

so that $W_1 = \dfrac{E_2^2}{4\omega Z_0}\cdot\left(\dfrac{\beta l - \sin\beta l\cos\beta l}{\sin^2\beta l}\right)$

Energy stored in C (W_2):

$$W_2 = \tfrac{1}{2}E_2^2 C$$

and $\tan\beta l = \dfrac{\sin\beta l}{\cos\beta l} = 1/\omega C Z_0$

Therefore $\quad C = \dfrac{\cos\beta l}{\omega Z_0 \sin\beta l}$

and $\quad \omega W_2 = \dfrac{E_2^2\cos\beta l}{2\,\omega Z_0\sin\beta l}$

Total stored energy (W):

$$W = W_1 + W_2 = \frac{E_2^2}{4\,\omega Z_0}\times$$
$$\times\left(\frac{\beta l + \sin\beta l\cos\beta l}{\sin^2\beta l}\right)$$

Dissipated Power (P):

If a resistance R is placed across AG, the terminals of the (lossless) resonator of Fig. 12, where the peak terminal voltage is E_2.

$$P = E_2^2/2R$$

Now that W and P have been evaluated, the Q-factor can be found.

$$Q = \omega\,W/P = \frac{R}{2Z_0}\cdot\left(\frac{\beta l + \sin\beta l\cos\beta l}{\sin^2\beta l}\right)$$

which is the expression used in section (3) with βl replaced by θ and appropriate values used for R.

If the $\frac{3}{4}\lambda$ mode is used (i.e. l is increased by $\frac{1}{2}\lambda$ sin βl cos βl and $\sin^2 \beta l$ remain as before and the only effect is to increase βl to $\pi + \beta l$. In general this term becomes

$$(\beta l + n\pi), \text{ where } n = 0, 1, 2 \text{ etc.}$$

15. Appendix 2 : Equivalent Lumped Circuits of Coaxial Resonators

In analysing microwave circuits it is often convenient to replace a distributed resonator by an equivalent parallel or series resonant lumped circuit. If for example we consider a coaxial line resonator in the vicinity of its resonant frequency and clear of other modes of resonance, the problem is to find the relation between the parameters L, C and R of the lumped circuit and those of the distributed line.

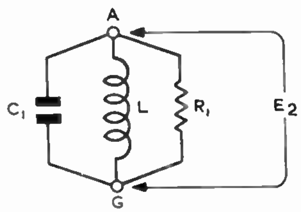

Fig. 13.—Lumped circuit representation of the resonator of Fig. 12.

For the equivalent circuit to have the same input impedance as the actual resonator near resonance, not only must the resonant frequencies be identical, but the stored energy and power dissipated must be the same for a specific terminal voltage.

That power losses must be identical is evident from the fact that the resonator and its lumped equivalent circuit must present the same resistance at resonance. The equal-energy condition is necessary to ensure that the shape of the input impedance against frequency response is the same in both cases.

As an example, the $\frac{1}{4}\lambda$ mode resonator of Fig. 12 (loaded across terminals AG by R) will be replaced by the lumped parallel resonant circuit of Fig. 13 and the values of L, C_1 and R_1 will be found.

From Appendix 1, the total stored resonator energy W of the distributed circuit is given by

$$W = \frac{E_2^2}{4\omega_0 Z_0} \cdot \left(\frac{\beta l + \sin\beta l \cos\beta l}{\sin^2 \beta l}\right)$$

where $\omega_0 = 2\pi f_0$ and f_0 is the resonant frequency

The lumped circuit must be such that with the same terminal voltage E_2, the equivalent capacitance C_1 stores this energy, i.e.

$$\tfrac{1}{2} E_2^2 C_1 = W = \frac{E_2^2}{4\omega_0 Z_0} \cdot \left(\frac{\beta l + \sin\beta l \cos\beta l}{\sin^2 \beta l}\right)$$

$$C_1 = \frac{1}{2\omega_0 Z_0} \cdot \left(\frac{\beta l + \sin\beta l \cos\beta l}{\sin^2 \beta l}\right)$$

C_1 does not equal C, the terminating capacitance of the coaxial line. This follows because the line has a distributed capacitance which must be allowed for in the equivalent circuit. However, if the frequency is such that $\beta l \rightarrow 0$

$$C_1 \rightarrow \frac{1}{2\omega_0 Z_0} \cdot (2/\beta l) = 1/\omega_0 Z_0 \beta l$$

$$\text{and } C = \frac{\cos\beta l}{\omega_0 Z_0 \sin\beta l} \rightarrow 1/\omega_0 Z_0 \beta l$$

Thus, as might be expected, the equivalent capacitance C_1 approaches the line terminating capacitance C, as $\beta l \rightarrow 0$.

The value of R_1 is evidently the same as R and the value of L in the lumped equivalent circuit must be such that the same resonant frequency f_0 is obtained. Thus L is given by

$$\omega_0 = 1/\sqrt{LC_1}.$$

Note that the Q of the equivalent lumped circuit ($Q = 2\pi f_0 RC_1$) will be the same as that of the distributed resonator, since C_1 was evaluated by equating the stored energies.

For a convenient method in deriving equivalent lumped circuits see Ref. 13 and for a number of worked examples see Ref. 12. In Ref. 11, many distributed circuit problems are simply explained in terms of equivalent lumped circuits.

Part 2—Microwave Disc-Seal Oscillators—will be published in a subsequent issue of the Journal.

ANNUAL DINNER OF THE RADIO INDUSTRY COUNCIL

A distinguished company attended the Annual Dinner of the Radio Industry Council at the Dorchester Hotel, London, on 23rd November, 1955, under the Chairmanship of Sir Edward Appleton, G.B.E., K.C.B., D.Sc., F.R.S., the recently elected President of the Radio Industry Council. The guests included members of both Houses of Parliament, representatives of learned societies, and radio manufacturers.

The Institution was represented by the President, Rear Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O., but the General Secretary, Mr. G. D. Clifford, was unavoidably prevented from accepting an invitation.

The Guest of Honour, the Right Hon. Sir Walter Monckton, K.C.M.G., K.C.V.O., M.C., Q.C., M.P., Minister of Labour and National Service, was introduced by Sir Edward Appleton, who reminded the Minister of "... the great recruitment needs of our industry. The radio and electronics industry is faced, even more than other industries, with a major problem in obtaining suitably trained man-power, and because it is expanding so rapidly has had, ever since the early days of the last war, to take very special steps in all possible directions to promote the flow of adequately trained recruits of all grades for essential research, development, production, and last, but not least, management."

In his speech, Sir Walter Monckton reminded his audience that 50 years ago there was no such thing as a radio industry. As an example of the increasing importance of radio and electronics to other fields of endeavour, the Minister stated that the development of Civil Aviation was really dependent upon radio and radar systems and it would be quite impossible to have a traffic control system such as there is at London Airport if it were not for the British radio industry. Electronics also played an important part in "... precise measurement, the accurate control of industrial processes and, what is very important to one aspect of my work, the remote control of dangerous processes. Above all this you have enabled automation to make tremendous strides, and there must come an outstanding contribution to that increase in productivity without which we shall not be able to maintain our standard of living, much less improve it."

Regarding the difficulties of recruitment to the radio industry, the Minister said "Do believe me, I have that constantly in mind, even though I cannot do all that you would wish me to do." He continued by stating that it was "... no small thing that the total number of people employed in the industry has doubled in the last seven years."

Referring to the development of automation, Sir Walter continued "It is the electronics industry undoubtedly which has given such an impetus to this, which will help to relieve the overall manpower shortage. But we all know, all of us who study this, that automation brings its own problems with it. There is the greatest need for smooth transition to its operation. On the management side there will be required a great deal of flexibility . . . automation itself will certainly bring with it an increase rather than a diminution of the need for skilled labour, for scientists and for technologists."

Finally, the Minister stated that the appeal of the industry must be to the youth of the future. The past history of the British radio industry was an encouraging thing "... but what we are really keen about and should be thinking about now, is attraction to youth to help us for the future development of your great industry."

Replying to Sir Walter's toast of "The Radio Industry," Mr. G. Darnley Smith, C.B.E., Chairman of the Radio Industry Council, expressed his confidence in the industry's ability to meet all the demands which would be placed upon it by the introduction of automation. He referred also to the industry's achievement in exceeding £3,000,000 worth of exports in the month of October.

The Postmaster-General, the Right Hon. Charles Hill, M.D., M.P., responded to the toast of the Guests, proposed by Sir Vincent Z. de Ferranti, M.C.

TELEVISION DEVELOPMENTS IN GREAT BRITAIN

Crystal Palace Television Station

The Television Advisory Committee has informed the Postmaster-General that the best technical solution to the problem of siting television stations in the London area is a single tower to carry the aerials for all the television services of the B.B.C. and I.T.A. The B.B.C. has accordingly agreed to make provision for the I.T.A.'s requirements on the 640-ft. tower now in course of erection at the new television station at Crystal Palace.

These arrangements will involve halving the size of the B.B.C.'s Band I aerial, and the top 250 feet of the tower will have to be redesigned; this will delay its completion by 18 months, and it will not therefore be possible for the new tower to be brought into service early next year as had been planned. However, in order that the new high-power transmitter which is being installed at Crystal Palace may be brought into service as soon as possible, the B.B.C. will erect a temporary mast and aerial, 250 ft. high, which will be close to the new tower. This temporary aerial system will be capable of a radiated power of 60 kW instead of the 200 kW which the B.B.C. had hoped to be able to radiate initially from the Crystal Palace. Even so, it is expected that, taking the London and Home Counties area as a whole, reception will be better than from the present Alexandra Palace station because the increased signal strength will mean less interference.

B.B.C. tests from the Crystal Palace site are expected to begin in the new year, and it is hoped to transfer transmission from Alexandra Palace to Crystal Palace in the spring. The B.B.C. will continue to use Alexandra Palace as a newsreel production centre.

When the new tower and aerial system in its new form come into service about May 1957, the B.B.C. will be able to raise the effective radiated power to 125 kW. Later on a further increase to nearly 500 kW, the maximum permitted by international regulations, is planned.

It has been decided that the new B.B.C. station will use the same method of transmission of the vision signals as is used at all the post-war B.B.C. television stations, the upper sideband being partially suppressed. In this respect it will differ from the existing station at Alexandra Palace, which transmits both sidebands equally. The new station will use the same frequencies and polarization as Alexandra Palace.

I.T.A. Plans

The I.T.A. is at present negotiating with the L.C.C. to acquire land near the base of the Crystal Palace tower for a building to house a new television station which will replace the temporary station now in service at Croydon; it is hoped to begin transmitting from Crystal Palace during 1957. The stations in the Midlands and Lancashire will, however, use the I.T.A.'s own masts.

The date for the opening of the Midlands transmitter at Lichfield was recently announced as 17th February, 1956, using the stand-by transmitter. Initially, therefore, the effective radiated power will be 50 kW; it is hoped that the main transmitter will be operating at its full power of 200 kW by June.

New B.B.C. Television Stations

Permanent medium power transmitters have recently been brought into operation at Meldrum, 20 miles North West of Aberdeen, and at Pontop Pike, near Newcastle-upon-Tyne. Both stations replace temporary low power installations and will operate at the same frequencies (Channels 4 and 5 respectively) with horizontal polarization. During December, v.h.f.-f.m. sound broadcasting in Band II was started from Pontop Pike.

An experimental service has been started in the Channel Islands with a station at Les Platons, Jersey. Programmes are obtained by radio reception direct from the transmitters at North Hessary Tor, South Devon, or Wenvoe, being picked up at Torteval in Guernsey and conveyed to Jersey by a microwave radio link. It is expected that the service will be more reliable when the full power transmitter at North Hessary Tor comes into operation early in 1956.

"Film Production for Television"

The British Kinematograph Society has announced that it is arranging a further course of lectures on film production for television. The lectures which are to commence on January 6th, 1956, at the Lighting Service Bureau, 2 Savoy Hill, London, W.C.2, will include: The Principles of Television and Cinematography, Lighting, and Sound Recording.

The enrolment fee for the course is one guinea for members of the Society and two guineas for non-members. Those wishing to enrol should apply to the Secretary, British Kinematograph Society, 164 Shaftesbury Avenue, London, W.C.2.

THE DEVELOPMENT AND DESIGN OF AN UNDERWATER TELEVISION CAMERA*

by

D. R. Coleman,† D. Allanson † and B. A. Horlock ‡

Read before the Institution in London on May 18th, 1955.
Chairman: Commander A. C. Pitman, R.N. (Associate Member)

SUMMARY

The operational requirements influencing the design are considered. The camera and associated electronic equipment follow standard television practice (625 lines 50 frames or 525 lines 60 frames). The mechanical problems of the camera casing are discussed and the handling arrangements for both diver-controlled and deep-sea cameras described. Some of the problems of underwater illumination are touched upon and a new type of remotely focused lamp referred to briefly.

1. Introduction

Public interest has been focused on underwater television in recent years as a result of two great disasters—the loss of H.M. Submarine *Affray* and the "Comet" air liners. The use of underwater television equipment was widely reported at the time but it should be appreciated that the development of underwater television was not a series of emergency measures taken each time a disaster of this nature occurred. It has been a slow, orderly and costly programme of research, experiment and testing in one of the most difficult applications of television. The *Affray* and "Comet" investigations have, however, emphasized that this new technique has immense possibilities, and a few of its other applications may be mentioned briefly to set the perspective.

A television camera may be left on the sea-bed for long periods for the unobtrusive observation of marine life.

A diver may be briefed by a preview of the scene below before he descends. His shot may be accurately positioned by television to enable him to descend directly to the required spot.

Experts who do not dive may observe conditions directly instead of relying on a verbal report from a diver who may be under stress.

Cameras may be sent into positions too dangerous for a diver to go. They can descend to depths beyond the range of direct human observation. Their underwater endurance is unlimited.

2. Problems Involved

Underwater television presents problems under three main headings:

(*a*) Electronics (or pure television).

(*b*) Mechanical design (underwater casing with glands, coupled with handling difficulties).

(*c*) Optics and underwater illumination.

Of these three, (*a*) is a well-known and highly-developed technique; (*b*) presents new problems but is fairly straightforward; (*c*) is still very much experimental and the most difficult.

ELECTRONICS

3. Choice of Camera Pick-up Tube

From practical experience with underwater lighting it is essential to use the pick-up tube with the highest sensitivity available. This is by far the most important factor in the choice of tube and automatically selects the image orthicon. Tests have been carried out using the staticon or vidicon tube and image iconoscope or photicon, but results have been inferior to those obtained with the image orthicon due entirely to their lower sensitivity to light. The reasons why it is undesirable to use a high intensity of artificial light are dealt with later. The image orthicon has one other useful advantage. It has gamma of unity which is higher than most other tubes. Underwater

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‡ Formerly with Pye Limited.
U.D.C. No. 621.397.5 (204.1).

objects often present very low contrast and the higher gamma picture results in increased differentiation of outline.

4. Early Equipment

Image orthicon camera chains have been standard broadcasting equipment for a number of years, especially for outside broadcasts. It was natural therefore that, at the commencement of experimental underwater television, a standard broadcast camera should be used and simply housed in a water-tight casing.

The circuits associated with an image orthicon camera chain (Fig. 1), together with a synchronizing pulse generator, are extensive and complex and less than a quarter of this can conveniently be housed in a reasonable sized camera. It is standard broadcast practice to house the remainder of the electronic circuits in several cases, each compact enough to be easily carried to a broadcasting site where they may be interconnected by multi-way cables to form a complete camera chain.

Such a chain as fitted to the Navy's deep-diving vessel H.M.S. *Reclaim* consisted of the following standard units:

(1) Synchronizing pulse generator,
(2) Camera control unit,
(3) Camera power unit,
(4) Picture monitor.

In addition to the camera one other special unit was provided in the casing. This was a remote control unit for optical adjustment of the camera and for the indication by remote means of the angle of tilt of the chamber; it also contained a leak warning device.

The optical arrangement consisted of a motor driven turret of four lenses any one of which could be brought into use by a push-button switch. As each lens came into the taking position, a gear in the centre of the turret was meshed with a quadrant gear on the lens.

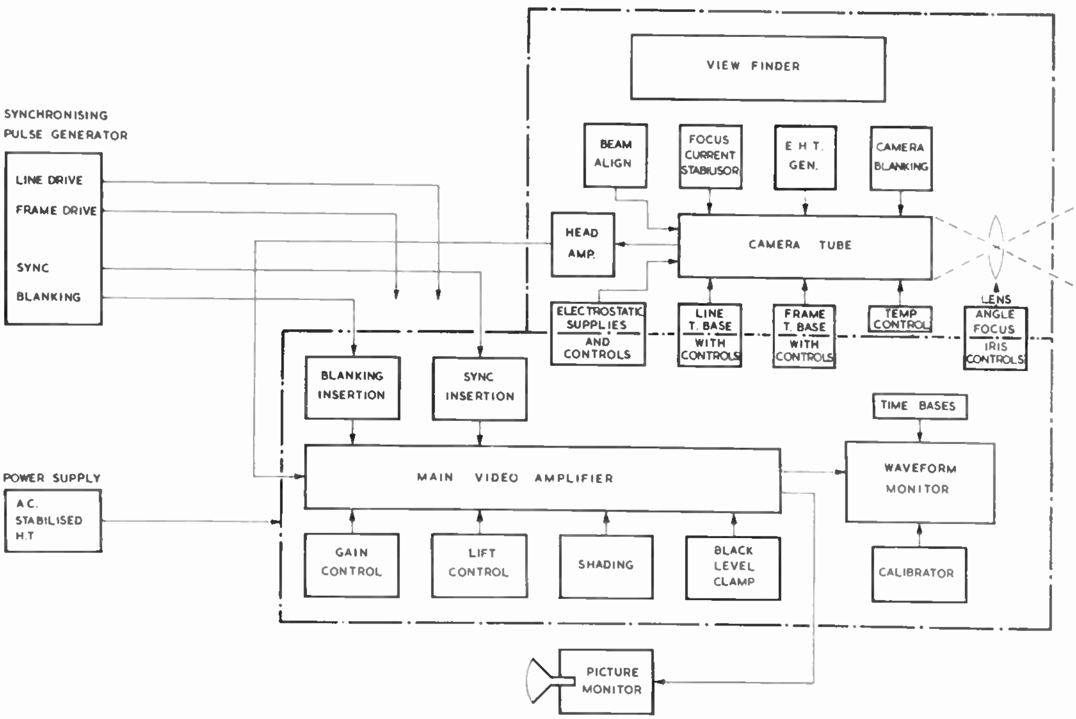

Fig. 1.—The basic standard television system, used in the underwater camera.

By this means the iris opening could be adjusted by a remotely operated motor.

Focus adjustment was accomplished by sliding the image orthicon with respect to the lens and this was driven by a servo-controlled motor.

All these remote controlled optical facilities were already incorporated in the standard broadcast camera and so no special development problems were involved in the electronic design of this camera.

5. Design Considerations for Marine Television Equipment

It was obvious after the initial successes of underwater television that it would be desirable to re-design the electronic circuits to cut out the superfluous broadcast features, to incorporate special requirements for underwater operation, and to design the camera to have the most desirable operating and handling features.

Trials conducted with the original apparatus under various conditions outlined the possibilities and limitations of underwater television. The design features to aim at became more clear as experience was gained. At the present state of progress the following considerations present themselves as governing the overall design.

(*a*) Many different cameras are required for various applications, for example: a casing with fins for work in a fast current; a small buoyant camera for hand manipulation by a diver; an ultra high pressure casing for extreme depths; special fixings for attachment to grabs, etc.; self-propelled cameras, and cameras with the ability to swivel and to be directed to look at any desired portion of the scene about them through horizontal and vertical angles of as near 360 deg. as is practicable.

It would obviously be uneconomical to produce a variety of cameras and the aim is to produce a camera head as small and as light as possible that can be bolted on to any external frame-work or underwater vehicle.

(*b*) Some of the work of the camera will be in highly dangerous conditions where it would be unwise to risk the life of a diver. The camera must therefore be considered expendible and its replacement cost must be kept to a minimum.

(*c*) If the camera is to be capable of operating at great depths the very long length of cable involved becomes a serious embarrassment when required for shallow working if it is permanently connected by a sealed joint to the camera. There are also advantages under different conditions attending the use of a light buoyant cable or a combined lifting and power cable. It is necessary then to provide an underwater connector so that different cables may be plugged into the camera as required. This also enables the camera to be transported separately from its cable and makes for compact units.

(*d*) It often takes a long time to manoeuvre a camera into a desired position. If a fault develops the camera must be hauled to the surface, brought on deck, wiped dry, the pressure-tight seal unbolted and the camera withdrawn from the case before servicing can begin. Every time the camera is opened up on deck further corrosion of electrical components may take place if spray is breaking over the ship. Obviously the camera must be as reliable and trouble-free as possible and this will be assisted if the circuits and components inside the camera are reduced to an absolute minimum even if this means additional complication in the ship-board units. This helps to meet requirement (*b*).

(*e*) The high cost of a set of underwater television apparatus will inevitably mean that it will be hired rather than purchased by the smaller organizations. The surface units must therefore be robustly housed and capable of standing rough handling. They also must be reduced to a minimum in size, weight and number to enable them to be transported or used in a small boat, or in a confined space.

(*f*) It would be an advantage for it not to be necessary to employ a skilled television engineer to operate the apparatus. Hence the complexity of control and maintenance must be reduced to a minimum.

(*g*) It sometimes happens that an emergency occurs in a remote part of the world and underwater equipment is required immediately. Normal air freight service to most parts of the world is available if all packages are limited to a maximum size of three feet by twenty inches by eighteen inches (90 cm × 50 cm × 45 cm) and a weight of 220 lb. (100 kg).

(*h*) The power supply available on board ship covers a wide range of voltages and frequencies and often it is not stable in either. The television equipment should be capable of running off the ship's supply whenever possible but a small petrol generator set should be available as an additional unit when no suitable power supply is available. To keep the size of the auxiliary generator down to easily transportable dimensions the total power consumption of the television apparatus should not exceed one kilowatt.

(*i*) For many applications it is a great advantage to have several picture displays. One monitor is needed by the control engineer, another may have a photographic camera mounted in front to obtain a permanent record of the passing scenes below. For delicate manoeuvring it is sometimes helpful if there are monitors available on the bridge and beside the winches used for lowering the camera and warping the ship.

(*j*) The usable definition varies enormously with conditions. Sometimes it is not possible to see more than a vague outline and, although in clear sunlit water it is often possible to obtain pictures of great clarity, there is a feeling that the definition of the 405-line system is inadequate. However, the apparatus should work on one of the standard systems in order that standard receivers and test gear may be used in conjunction with it. If a great increase in definition is made then the video amplifiers and the line time-bases become more critical and the delay problem in long lengths of camera cable becomes difficult. For these reasons 819 lines is not considered a practical system at the present stage of development. The standard of 525 lines 60 frames (or 625 lines 50 frames) would seem to offer the best compromise.

(*k*) For some purposes a photograph of an underwater object may be required to be taken from a monitor screen and this may be used to measure off angles and distance ratios between certain features of the object. The accuracy of the results will depend on the linearity of the time bases and the geometrical distortion present in camera and monitor scans. The scanning error should be kept within one half of one per cent.

(*l*) It is sometimes useful to have attached to the camera a pressure gauge to indicate depth, a tilt indicator, and a gyro direction indicator, each of these registering remotely. These should be considered as additional refinements and should not be allowed further to complicate the camera head. They may be provided in a separate unit which can be attached to the camera chamber.

(*m*) Manoeuvres are often complicated by the presence of large numbers of cables necessary for the operation. The ship may have as many as six anchor cables out. There may be one or more grappling lines. There may also be a diver's air line and his shot rope. It requires great skill to avoid the fouling of lines. It thus becomes of great importance that the television camera should have, if possible, only one line. This will take the form of a lifting rope with an inner core of electrical conductors in a pressure resistant insulating sheath. There should be sufficient conductors to feed power to the lamp and to carry the information from the direction indicators as well as to carry the main camera head supplies.

6. Detailed Description of Equipment

We will now consider how far the design features of the latest underwater equipment fulfil the foregoing requirements, dealing first with the electronic design unit by unit.

6.1. *The Camera Head—General Arrangement*

This is cylindrical in form and the components are arranged to use this shape to the best advantage. The length was kept to a minimum and was determined by the total length of the image orthicon tube with a lens system in front and a certain amount of cabling behind. The diameter was governed primarily by the amount of volume required to produce a buoyant unit in a casing whose features are described later. A four-lens turret enables changes of acceptance angle to be made underwater. The circular nature of the turret fits in well with the cylindrical construction and off-setting the tube from the centre line leaves maximum room for the other components.

Remotely switched motors with gearing are provided to turn the turret and to operate the iris of the taking lens. Focusing is accomplished by means of a servo-controlled motor moving the pick-up tube with respect to the lens. The remaining space was available for the electronic circuits that had essentially to be located in the camera. These consist of:

(1) A two-valve head amplifier to deliver the video signal at an amplitude of 0·5 volt into the transmission line. Partial correction of high frequency attenuation across the image orthicon load is achieved by negative feed-back.

(2) A target-blanking amplifier consisting of

two double-triodes deriving blanking pulses from frame and line flyback waveforms.

(3) The line scan saw-tooth generator, output and damper stage (3 valves).

(4) A protection circuit to cut off the beam in the event of scan failure.

Experience has shown that the components in a submerged camera tend to run cool and a heater surrounding the image orthicon target, switched by a relay, is provided to maintain the target temperature within the operating range. To keep down the number of conductors in the camera cable certain preset controls are located in the camera.

A leak indicator is incorporated. This is a most valuable and a very simple device, which consists of a piece of blotting paper sandwiched between a metal plate and the earthed metal chamber. A potential is applied across the blotting paper. When it becomes damp a current flows and a relay in the control unit switches on a warning buzzer.

The frame upon which the camera head is built will slide into a variety of chambers developed for special applications—two of which are described later.

6.2. *The Control Unit*

This is contained in a case measuring 22 in. × 13 in. × 14½ in. (57 × 33·5 × 37 cm). The power intake covers a range of 80 to 250 V a.c. 45 to 65 c/s. The unit provides stabilized h.t. supplies and a fixed a.c. voltage to power its own circuits and those of the camera. The control unit circuits consist of:

(1) Image orthicon focus current stabilizer, electrode potentials and e.h.t. supplies.

(2) Amplifier for the servo optical focusing mechanism.

(3) Blocking oscillator divider type of synchronising pulse generator switchable to 525 lines 60 frames or 625 lines 50 frames systems.

(4) Video amplifier with compensating filters for the head amplifier input attenuation and for the attenuation of various lengths of camera cable.

(5) Mixers for the injection of frame and line shading, blanking and synchronizing signals.

(6) The frame scanning generator for the camera tube.

(7) An oscilloscope for monitoring frame and line waveforms, for setting up the dividers and for fault tracing.

(8) A voltmeter for setting up the a.c. input taps and for fault tracing.

The controls for setting up the picture and for control of the camera are distributed on the front panel. The optical focus control knob is calibrated in feet to enable an estimate to be made of the distance of the object being viewed.

When dealing with various lengths of camera cable from a few hundred feed to 3,500 feet in length the delay on the camera video signal received at the control unit makes special timing correction necessary. This is automatically arranged as follows. In the camera cable which is of a standard type as far as conductors are concerned, are three coaxial lines. A line-drive pulse is sent down line A from the control unit. On reaching the camera this pulse triggers off the camera line-scanning generator and then returns to the control unit via line B, where it is terminated. This delayed pulse is used to generate blanking, clamp and synchronizing pulses. The video signal arrives from the camera via line C with the same delay as the drive pulse for all lengths of cable.

There is one video output at a level of one volt positive polarity with 30 per cent. synchronizing pulse amplitude.

The total power consumption of the control unit and camera together (without the lamp) is approximately 450 watts.

6.3. *Monitors*

These are standard monitors as used by the broadcasting organizations. Their size is 22 in. × 13 in. × 14½ in. (57 × 33·5 × 37 cm) and the picture is displayed on a 14-inch rectangular cathode-ray tube. Input and ouput video sockets are connected in parallel so that several can be worked together on the loop-through system.

6.4. *"Flash-it-on" Unit*

The function of this device is to record photographically the pictures received. The basis of this is a standard monitor containing in addition a dummy c.r.t. gun. When pulsed the beam of the picture c.r.t. is suppressed and that of the dummy is switched on. The purpose of this is to keep a constant load on the e.h.t. supply and so maintain its regulation.

A frame-work forming a hood extends outwards from the screen of the monitor and at the end of this is fixed a recording camera loaded with up to 200 frames of 35-mm film. This camera is electrically operated synchonously with the "flash-it-on" device. A pulse initiates a sequence of events as follows:

(*a*) The picture is suppressed.

(*b*) The recording camera shutter is opened.

(*c*) One complete field i.e. interlaced picture, is flashed on the screen and this exposes the film.

(*d*) The recording camera shutter is closed and the next film frame wound forward.

(*e*) The monitor picture is restored.

Individual recordings may be made in this manner by pressing a switch as and when desired. Alternatively the device may be set to record continuously and automatically at a repetition rate which may be set between one picture per second and one picture per 30 seconds. A viewing aperture is arranged in the hood to enable the monitor picture to be set up and checked.

7. Remote Optical Controls

Referring to Fig. 2 the principle of operation of the three controls can be seen. The design is influenced by the necessity to use as few wires as possible. It must be appreciated that there is in the camera cable an earth connection and also two lines for a.c. power supply to the heater transformer. It will be seen from the diagram that one extra lead is required for the turret positioning motor and one more for the iris motor. Two additional leads are necessary for the servo-focusing system which operates as follows:

A transformer winding in the camera develops 12 V across a feed back potentiometer shunting the secondary winding. A similar arrangement in the control unit develops 12 V across the manually-operated focus potentiometer in the control unit. One side of each of these windings is connected together. It will be seen that if no voltage is produced by the generator winding in the camera, the input to the amplifier will always be zero when the sliders of the potentiometers bear the same relationship to each other. If the focus potentiometer is moved an a.c. signal will be fed to the amplifier. Its output will be delivered via the second camera cable lead to drive the motor. The motor is geared to the camera potentiometer and moves its slider in such a direction that the amplifier input is reduced to zero. As long as the motor is turning a small

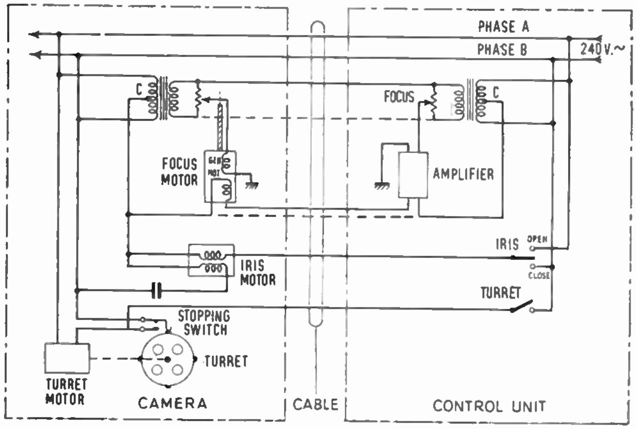

Fig. 2.—Optical control circuits.

voltage is produced by the generator. This is added in anti-phase to the amplifier input voltage and it acts as a feedback control damping the mechanical momentum of the system. By this means quick and precise positioning of the pick-up tube with respect to the lens can be remotely controlled.

The iris motor is a reversible split phase machine. One winding is continuously energized via the series capacitor which shifts the phase of the current 90 deg. with respect to the voltage supply. One side of the other winding is connected to a centre tap of the a.c. supply, while the other side is switched, via the single lead, to either one phase or the other of the a.c. supply to close or to open the iris.

The turret is rotated by a similar motor. It drives in one direction only and when the turret is in any of its four operating positions a stud on its periphery opens a micro-switch. A control switch parallel with this is closed and immediately opened when it is desired to change a lens. As soon as the turret starts to move the micro-switch closes and power is thereby maintained to the motor until the next lens station is reached.

MECHANICAL DESIGN

8. Design Considerations

As stated in the Introduction, an underwater camera unit consists essentially of a watertight pressure casing which envelops an electronic, mechanical, optical assembly called for convenience a "camera head." The head illustrated in Fig. 3 has universal application and may be used in pressure casings ranging from buoyant diver-controlled camera units to deep-sea remotely handled units capable of working at depths of 3,000 ft. (915m.).

The development of a buoyant unit, a deep-sea unit (which has been successful at 1,050 ft.) and the design details of a universal camera head (now in batch production) will now be described. The special features of the two types of pressure casings are dealt with later, but some observations regarding the buoyant unit are necessary to show how our attempt to meet this requirement has influenced the design of the camera head.

9. Buoyant Camera Units

A diver-controlled camera must be:

(*a*) Physically as small as possible, and of a shape which will allow effortless manipulation under water.

(*b*) One to one-and-a-half pounds (0·45–0·7 kg) positively buoyant.

(*c*) Trimmed to adopt a horizontal attitude longitudinally and transversely when submerged.

(*d*) Able to withstand severe shocks.

(*e*) Provided with two hand grips.

(*f*) Capable of control using one hand only.

(*g*) Provided with detachable lighting equipment.

(*h*) Able to withstand external pressures of 150 lb/in.^{2} (10·5 kg/cm^2).

It was soon obvious that considering (*a*), (*b*) and (*c*), a camera head would have to be developed in a form that in size and weight distribution would match the requirements of a casing which embodied all the above features. At first this appeared to be a "cart before the horse" method, but upon reflection, it is certain that it was in fact the correct procedure.

The design parameters imposed upon the camera head by the first experimental casing have been perpetuated throughout its development. The casings on the other hand have been changed in detail largely as the result of manufacturing problems. Each change so far, has added to the total weight of the casing, and in order to maintain the desired buoyancy, the volume of the casing has had to be increased. The latest casings have a displacement one-fifth greater than the original model, which is a disadvantage and departs from the ideal (*a*) but helps considerably the achievement of (*c*), the importance of which cannot be overemphasized, for unless a balanced condition is obtained the camera unit cannot be controlled underwater by a diver without fatigue and embarrassment.

The first experimental casing was fitted with a window of armoured plate glass with a clear diameter of 3¾ in. (9·8 cm); the window was offset from the centre, and the casing was proportioned to displace approximately 1 cubic foot (2830 cm^3); it weighed 21¾ lb. (9·85 kg)

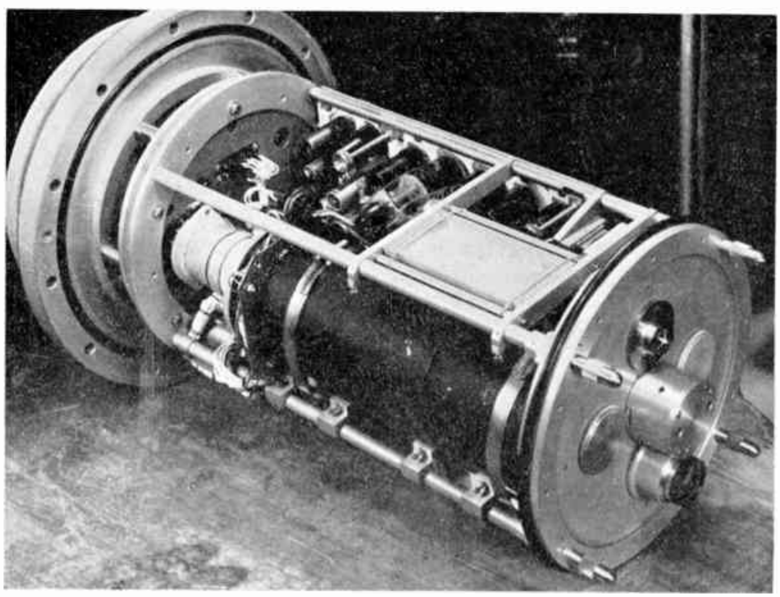

Fig. 3.—Universal camera unit.

in air, and required 43½ lb. (19·8 kg) of ballast to sink it in water. In this fashion the maximum weight of the camera head was fixed at 42 lb. (19·1 kg), and the dimensions of the head at 10⅜ in. diameter × 18½ in. length overall (40·8 × 7·28 cm). The major electrical and

Fig. 4.—Experimental buoyant unit.

mechanical components were then weighed and their disposition determined to give a low centre of gravity relative to the centre line; by correlating the centre of buoyancy of the casing to the centre of gravity of the camera head the unit was made to adopt the desired attitude in water. Fig. 4 illustrates this and shows the experimental unit in use during early trials. In operation, longitudinal balance is slightly affected by the fore and aft movement of the relatively heavy focus and deflector coil assembly, and by the varying influence of tidal water forces upon the camera cable. This effect is minimized in practice by securing the cable at a convenient point either to a shot line or to the driver's breast rope. The free loop of cable snakes under his arm, and in this manner he is able to manoeuvre the camera unit without difficulty.

10. The Camera Head—Mechanical Layout

This is illustrated in Fig. 5 and is shown in its normal operating position viewed from below. It will be seen that the image orthicon focusing and deflector coil assembly, which is the heaviest and by far the largest component, is offset to the left of the axis on a horizontal centre line. Immediately below is its carriage slide, slide rails, and the gearing connecting the carriage to the servo gearbox which is to the right of the vertical centre line. Immediately behind the turret attached to the camera front plate is the turret drive gearbox with its split phase motor and solenoid operated brake; midway along the length of the camera again to the right of the vertical centre line, is the heater supply transformer mounted upon a heavy gauge brass chassis.

These heavy components control the balance of weight distribution; their relative weights and disposition within the confines of the head achieve the low centre of gravity and longitudinal and transverse balance referred to earlier. All other components are either of trivial weight, or are concentrically mounted and have little influence in this respect.

The front and rear plates are circular in shape. The front plate is a complex assembly mounting the turret and turret drive, the lenses,

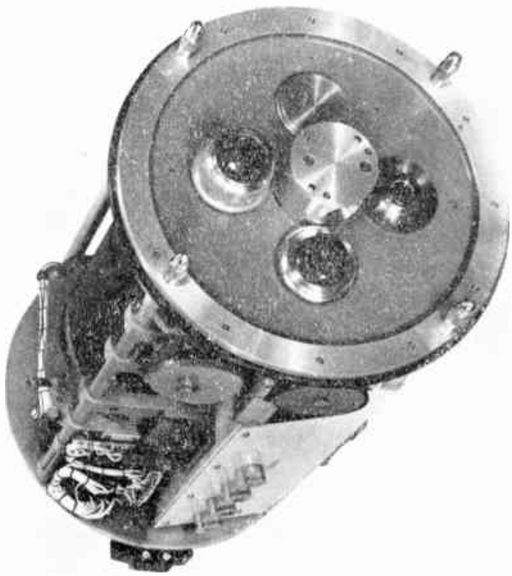

Fig. 5.—Camera head viewed in normal operating position from below.

iris gearbox, control switches, condensers etc., and if required, a four-station remotely-operated colour filter disc. The plate is attached by four finger-screws and is located by spigots to ensure accurate optical and mechanical alignment.

Five accurately proportioned stainless steel tubes provide an elastic suspension for the complete head assembly. Two of these tubes, braced by four cross members, form, when bolted to the orthicon carriage rails, a light yet robust structure which mounts the focus and deflector coil assembly and the servo gearbox. The other tubes positioned at 90 deg. to each other give support to the front plate assembly and the chassis; all five tubes are linked together at the front of the head by a light "C" shaped frame; at the rear end they are anchored rigidly to a substantial metal ring which in turn is secured to the casing head.

This inherently flexible construction protects the delicate components from the severe accelerations and shocks encountered during transportation and undersea working, and it is in conformity with the ideal circular construction, a feature that will be perpetuated in future designs.

For ease of operation, maintenance and manufacture a number of components and assemblies common to standard broadcast cameras are used in its construction. Time-proved production units ensure reliability, and although it was tempting at the start to produce special parts to satisfy a desire for elegance, it was realized that such pandering would earn little appreciation if the price was doubtful reliability. Another consideration is of course the economic one for, by adopting standard parts wherever possible the initial cost is very appreciably reduced, replacements are less expensive and more readily obtainable. Replacement assemblies, which can be fitted by relatively unskilled personnel quickly and with certainty are essential if equipment is used in remote parts or away from shore. To this end the camera is made to be dismantled easily into four main units (Fig. 6) without the use of any special tools and packaged replacements are held available for 525/625 line units at various centres round the world.

11. Handling Problems and Cable Design

Early underwater cameras had as many as four lifting wires and cables attached to them; in operation these were bowsed together at frequent intervals to prevent them streaming in the tide. Such procedure is time-consuming during lowering and raising the camera unit and if not carried out effectively, seriously interferes with control underwater. To reduce the number of wires and cables to a minimum has been an obvious requirement since the early days, but until the advent of the light-weight camera it was not feasible to consider a combined lifting rope and camera cable. Recently such a cable has been produced and tested fully in operation. This cable considerably improves handling on deck and underwater, and enables the camera unit to be lowered or raised at speeds up to 180 ft per minute (54·8 m/min.), at least ten times faster than by separate wire methods. A simple termination for the outer lifting sheath is employed which on test will withstand a static load of 32 cwt. (1625 kg). This cable, produced by British Insulated Callenders Cables Ltd., is terminated at the camera unit

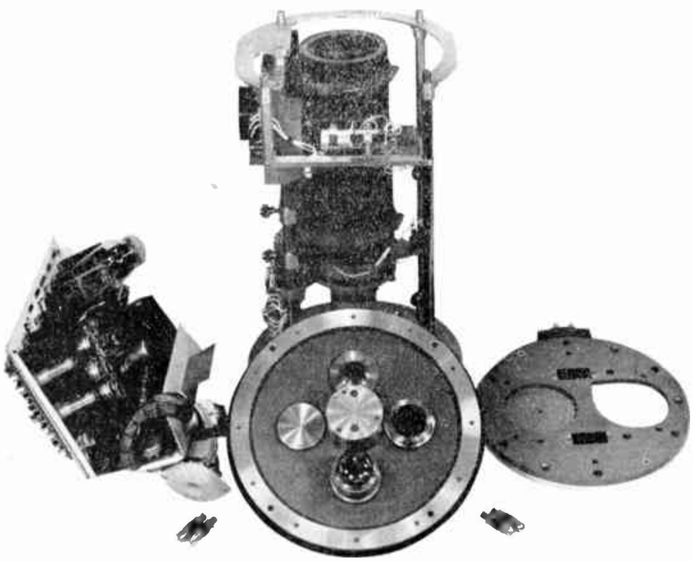

Fig. 6.—Camera head main assemblies.

end by a waterproof socket which mates with a 36-pin Vitroc plug. This plug, which occupies the centre of the casing end plate and is pressure tight to 650 lb/in.^{2} (45·7 kg/cm^2), gives protection in the event of underwater damage to the camera cable and hermetically seals the unit at all times. A four-pin version of this seal is used for the outgoing lamp supplies and provides a buffer against water pressure should damage to the lamp window or its armoured cable occur.

An underwater camera unit which is relatively light in weight when submerged, is lively in its response to control from above. As a result it can be trawled easily at appreciable depths and at speeds up to 2 knots. By employing a single cable, which can be rapidly fed out or hauled in, irregular sea-beds and underwater obstacles can be traversed without difficulty.

12. Casing Design

The camera casing is designed to stream facing away from the direction of travel; two triangular fins which support the lamp act also as a keel and stabilize its motion through the water. The stirrup, by which the camera is supported, is provided with a quadrant to enable the camera to be fixed in certain attitudes from horizontal to vertical or left free to swing on its pivots; the side members of the stirrup are shaped to guide the camera casing free of obstructions which may occur above camera height whilst underwater.

The casings for the buoyant and the deep sea units are produced in an aluminium alloy which is very resistant to the corrosive effect of sea water and stainless non-magnetic steel is used for all bolts and fitments, the grade of steel used being chosen primarily because of the low potential difference existing between it and the aluminium alloy. Electrical insulation is provided as an additional safeguard against galvanic action wherever possible. Anodising and painting are considered unnecessary for protection, but hand held camera units are treated in this way in order to save elaborate finishing processes which would be required to present an acceptable appearance in a natural finish.

The buoyant casing is constructed from castings, rod and sheet bonded together with epoxy resins. The tapered cylinder used in earlier models was rolled from sheet and argon-arc welded along the seam. This was never a completely satisfactory method of manufacture because the alloy, chosen for its resistance to corrosion, did not exhibit good welding properties, and hair cracks and pinholes were often revealed during pressure testing. This defect has been overcome by deep spinning the cylinder, thus eliminating the seam and resulting in a stronger construction and the avoidance of suspect welds. The deep-sea casing is machined from a solid forged billet and is bored to leave an end plate 1¼ in. (3·18 cm) thick. Two tapered grooves are machined in the bore to accommodate the leak indicator ring and to locate positively the terminal block and spring contacts for the lamp and direction indicator supplies. A recess is machined into the face of the end plate in which the armour plate glass window is fitted. The window is mounted on 1/32 in. (0·795 mm) thick Nebar jointing sheet, a rubberized cork material which has been found in practice to be much superior to rubber for this application. Thin material is used for deep sea work to reduce capilliary action which has been observed to occur when thicker section sealing rings were used. The rim of the glass disc is ground to a smooth finish and the edges chamfered, a strip of jointing being cemented to the rim to prevent any possibility of glass to metal contact.

OPTICS AND UNDERWATER ILLUMINATION

13. Optical Considerations

Optically corrected windows are not considered for deep working and are not used because of expense, bulk and the difficulty of sealing them against high pressures. Polished plate glass is also not favoured because the extra thickness which is needed for similar working pressures complicates the clamping ring design. On a small size casing of this type with an offset window and using wide angle lenses it is not possible to increase the aperture of the clamp ring sufficiently to avoid field cutting and still retain the window in a satisfactory manner. In any case, it is doubtful, at the present state of underwater television development, whether striving for optical perfection of this order is worthwhile, as the theoretical improvement obtained is vitiated by the difficulties of lighting the underwater scene.

14. Underwater Illumination

Illumination, whether for television or cinematography presents special problems in underwater work at depths beyond which the surface light is lost. A television camera, like the cine camera, is dependent upon light and water-clarity for range of vision but it is more flexible in this respect due to its superior light sensitivity and contrast ratio and to the fact that the information it gives is presented instantly and can be corrected or adjusted to match a change in conditions.

In clear sea water in sunlight, sufficient illumination to provide a picture of reasonable contrast permeates to 180 ft. (55m) while at 350 ft. (107m) it is still possible to see vague outlines. However, because underwater television can be used at all times of day and night and at depths considerably in excess of 180 ft. underwater lighting is provided as an integral part of a deep-sea unit. On deep-sea units the lamp housing which is supported on triangular fins can be fitted with either a mercury-arc source consuming approximately one kilowatt or a variable beam incandescent spot source of relatively low power 150-250 watts.

Different kinds of light source have been used experimentally in conjunction with underwater camera heads of this type in Britain, America, Canada and Japan. Xenon, sodium, mercury-vapour, mercury-arc, tungsten-arc, and high and low wattage tungsten filament lamps have been tried and their performance studied. Some of these sources have special characteristics which, by controlled application, may offer the advantage of improved range under certain water conditions. However, as discharge and arc lamps usually require ballast resistors, chokes or transformers, and relatively high striking operating voltages and currents, and can sometimes be used only in restricted attitudes, their limitations tend to offset any slight advantages they exhibit. In practice it has been found that the low-wattage incandescent lamp with remotely focused beam is the most useful general purpose source. With a lamp of this type mounted some distance ahead of the camera, as little as possible of the water between the lens and the object is illuminated and an appreciable reduction of back scatter achieved. Beam focusing in combination with simple dimming facilities gives considerable control over a variable which when properly used in conjunction with a remote iris control profoundly influences the range and quality of the picture. It was found difficult to achieve the desired even spread of light over the areas covered by the chosen range of lenses when using standard form lamps, the physical dimensions of their envelopes preventing a sufficiently close approach of the spot source to the reflector for the widest angle beam. This

Fig. 7.—Deep sea unit with remotely focused lamp and combined lifting rope and supply cable.

objection was largely overcome by the production with the help of the British Thompson Houston Company of a special lamp of small physical dimensions, water cooled, and fitted with a shield to cut off extraneous forward light. This is shown in Fig. 7. It cannot be claimed at this stage of development that the light distribution is completely uniform over all the areas covered by the beam; nevertheless, this controlled-beam lamp gives a remarkable improvement in range and contrast over previous underwater lighting arrangements and results indicate that, despite the extra mechanical and electrical components necessary for the focusing device and the complication brought about by water cooling the light source, the lamp has the ability to give light where it is wanted and at the most suitable brightness level.

In most waters, and in particular very clear water, increased brightness does not greatly improve the range of vision or contrast. Picture contrast is however improved by using a less intense light in conjunction with a wider lens aperture. During experiments in the extremely clear waters off the West coast of Scotland, a greater forward range was regularly obtained using a mercury-arc source with filters and beamed to match the acceptance angle of a 39-mm. lens. This intense light source at a depth of 350 ft. gave almost twice the range obtainable with an incandescent lamp of the same power consumption. It seems however to be an isolated example, for in no other water has such an enormous improvement been achieved over incandescent lighting. This type of lamp with its compact light source will perhaps have wider application in the future when units are built to operate at great depths.

15. Conclusion

In this short paper an attempt has been made to describe the features of a modern underwater camera head and two underwater units. It is hoped that the attempt has been worthwhile and that the reader has been given a glimpse of the fairly rapid developments that have taken place over a short period of time. Many excellent articles and papers have been written describing the development of underwater television, particularly those dealing with the two major disasters in which it played a prominent part. Its present limitations are fully realized by all those engaged upon its further development, but now that it has awakened interest all over the world it is reasonable to suppose that more effort and financial support will be forthcoming with the result that some of the problems of underwater lighting and control will be resolved within the next few years.

16. Acknowledgments

In conclusion the authors wish to thank their colleagues at Pye Ltd. for their help in preparing the paper and illustrations, the Technical Director, Mr. B. J. Edwards, for his interest and encouragement throughout, and the Board of Directors for permission to publish this paper.

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DISCUSSION

G. G. MacNeice: The reason why the early underwater cameras were large and heavy should be explained. At the time of the *Affray* disaster in 1951, when the Admiralty decided to start underwater television in this country, we had to be content to use the only cameras obtainable in a hurry: these were of the standard type as used by the B.B.C. for outside broadcast work. It was literally a case of the square peg in the round hole because the cylindrical pressure-resistant casing had to be large and bulky to encompass the roughly cubic shape of the standard camera. Later, when time permitted, the obvious step was the development of a camera head to fit within a small-diameter cylindrical casing.

Now that the manufacturers have simplified and reduced the size of the camera, I would like to see them turn their attention next to the control end of the chain. A number of refinements—interlacing for instance—although desirable for broadcast work, could well be dispensed with in the closed circuit underwater application, thus reducing the equipment nearer to the ideal "one-box" control as in a Vidicon chain.

While agreeing that the Image Orthicon is the most suitable tube for the majority of this work, I think it should be recorded that the first body to consider seriously using underwater television in this country was the Scottish Marine Biological Association, who, with the backing of the Development Commission, purchased an equipment using the C.P.S. type tube. Despite its need for high illumination the fine detail and good picture gradation which can be achieved has enabled Dr. Barnes to obtain many remarkable studies of marine life in the course of his researches at Millport with this equipment.

From the point of view of the user, I am very pleased to see, at last, the introduction of both the underwater cable coupler on the camera and the combined supporting and supply cable. These developments should facilitate the handling in service.

I would ask Mr. Coleman if it has occurred to him that a coupling could be introduced between the lens selection mechanism and the lamp focus control so that the cone angle of the light beam would be automatically adjusted to suit the field of view of whichever lens was in use. When using the longer focal length lenses, such an arrangement would reduce the amount of water unnecessarily illuminated in front of the camera which might effect a useful reduction of back-scatter.

Mr. Coleman mentioned that advantage had been gained by dimming the light to a yellow colour. I am interested by this statement because, in practice, absorption of the light is usually of no consequence and is certainly negligible compared with the effect of scattering, but as the particle sizes are large compared with the wavelength of light, it follows that the scattering is completely non-selective; therefore the use of light of any particular colour offers no advantage. This has been substantiated by our experiments in British coastal waters. However, in certain special areas where the water clarity approaches that of distilled water, the only scattering being molecular, absorption then becomes significant and in the case of sea water, a selective transmission in the yellow/green becomes apparent. Hulbert has published some work on this subject. Theoretically, there should not be any advantage in using yellow illumination except under these rather exceptional conditions. I would like to know the water clarity conditions in which the author claims to have gained an advantage by dimming his light.

F. I. L. Knowles asked what operational ranges were achieved with the equipment and suggested that these should be related to an object presenting a fairly high contrast with the underwater background at depths of 50-150 feet in clear water. He also wished to know the raster frequency and the duration of one raster.

W. Kiryluk (*Associate Member*): I would like to know how the underwater camera is steered while it is at considerable depth. Is it possible, for instance, deliberately to direct the camera at the object to be televised?

I wonder whether it is practicable to fix two small propellers to either side of the camera, and by remotely operating one of them at a time, either to keep the camera stationary against the currents or to direct it at will by revolving it around its own axis. The same action could be obtained by replacing the propellers by remotely-controlled outlets of compressed air, thus producing the necessary torque. These methods of control could only be possible in clear water, so that no mud is stirred up to obstruct the vision.

Finally, what is the present method of making observations while the camera is stationary?

J. C. G. Gilbert (*Member*): In March 1955, Sir Robert Davis delivered a lecture at the Royal Society of Arts on "Recent Developments in Deep Sea Diving" in which he gave a historical background of the application of television to operations under the sea.[5]

When the project was taken up seriously in 1949, the only suitable cameras available in England were of the type used for television broadcasting and due to the demands of the B.B.C. it was some time before a camera, with its ancillary monitor, scanning generator and power supplies, was obtained for experimental purposes.

The first camera that was built used a standard studio type camera with an image orthicon tube with remote control of aperture and focusing. The outer casing consisted of a welded steel cylinder with an offset plate glass eye mounted immediately in front of the camera lens. This camera was operated in the horizontal sense and a multi-way cable connected the camera to the control gear on the deck of the ship.

In spite of the background knowledge gathered over 100 years by the diving equipment company, it was found that the camera could not be controlled with any degree of accuracy when suspended at the end of a cable 300-400 feet in length. Normally the camera took up an attitude in the direction of the local current and therefore it was impracticable to look in any other direction except that of the current. It was therefore decided that a completely new approach should be investigated in which the camera was to be used vertically. By means of a rotatable prism it was possible to give all-round viewing and by altering the angle of the prism it became possible to view a solid hemisphere.

In the earlier models such as that used during the recovery of the wreckage of the Comet at Elba, the design of the periscope was such that it gave a rather restricted aperture but in the current model this difficulty has to be overcome by re-calculation of the optical system. By means of selsyn motor drives it is now possible to look in any direction from the vertical to about 10° above the horizontal and, by remote control from the surface, to continue looking at the object irrespective of movement of the camera.

C. Ridgers (*Associate Member*): Having seen photographs taken of the sea bed of a bay on the South Coast of England, I am impressed with the stability of the underwater television camera since these recordings showed very clearly minute details of life such as starfish and their spines and also pebbles and the markings on them. I am nevertheless surprised at the efficacy of the simple arrangements used to stabilize the camera.

I would point out that a further method exists for the manoeuvring of mechanisms under water whereby for rotation, a servo-motor hunts continuously against the thrust of three or four paddles extended horizontally in the water, the reference being a flux gate compass or similar device in the submerged unit. The bearing of the camera is of course a function of the setting of controls on the surface which are in the feed-back loop.

AUTHORS' REPLY

Early underwater camera units were large and bulky, as Mr. MacNeice has explained, because it was expedient in the early stages of development to use standard broadcast equipment. Experience with these early units emphasized the need for specially designed small units and led directly to the development of the camera head described in the paper, which incidentally was the first image orthicon head to be designed expressly for underwater use. Since its inception in 1952 three other basic camera heads have been designed and developed for special applications, but because of its universal application, the original design has not been superseded. In parallel with the design of these heads has been the development of the control unit briefly described in the paper. Simplified as far as is practicable without sacrificing stability and operational facilities, it conforms to the ideal "one box" construction with the reservation that a separate display monitor is required. This was thought to be the most flexible arrangement. It allows a choice of monitor, size of screen, etc., and makes for smaller and more portable units.

It is doubtful whether more than two valves could be saved by discarding the principle of interlaced scanning. Moreover, to achieve the same definition, within the same bandwidth, using a sequential system, the frame repetition frequency would be only 25 cycles per second. Flicker from such a low scanning rate is most objectionable when viewing images of very low contrast.

A spiral scanning system has been advocated, but, whilst this has the attraction of simplicity, it has serious limitations arising from the great changes of scanning velocity inherent in the system. A normal interlaced scanning system has the considerable advantage of using standard display monitors which are reliable, economical and readily available.

Since the raster frequency is the same as that of the standard broadcast system in this country, one frame is presented in 1/50th second and one complete interlaced raster in 1/25th second.

In the waters off the coast of Florida, in the Mediterranean, during the Comet search off Elba, and in the Lake of Zurich, improved range of vision was obtained by under-running incandescent lamps. In these cases the water was not exceptionally clear. At Elba a single 150-W 230-V reflector floodlight, with a potential of 180-185 V at its cap was used throughout the operation. A measured visibility of 22 feet was obtained by lowering the camera unit vertically until its 12-ft. probe was just touching the sea-bed, then raising the camera foot by foot until the detail of the sea-bed disappeared. The supply to the lamp was then raised to give 230 V at its cap and the experiment repeated. This increase in brightness resulted in a loss of range of some 4 feet. A side-by-side comparison with the periscope camera employing six similar lamps showed that its range could be increased by switching out four of its lamps. In the other locations, whilst no direct measurements were taken, it was noticeable that under-run lamps gave better results.

Automatic adjustment of the light cone to match the angle of the operating lens might seem to be desirable, but the extra complication was not thought to be worthwhile. With remote beam focus it is possible to achieve infinitely variable control whichever lens is in use, whereas precise matching might not provide the best result under all conditions.

Replying to Mr. Kiryluk, camera units of the type described in the paper cannot be steered at considerable depths. They are designed to stream looking into or away from the direction of the current.

This limitation has been overcome by the introduction of the underwater vehicle to which a camera unit is attached. Three experimental underwater vehicles exist. Two of these are driven by screws mounted directly on the shafts of submersible motors, the third is driven by a combination of screws and compressed air. Development of these and similar units is proceeding apace and no doubt details will soon be appearing in the technical press. In fact one early American unit has already been described.[6]

It is interesting to speculate upon the eventual answer to the problem of control of a camera unit underwater. We believe that the solution will be found by providing a camera unit of the smallest possible size, mounted universally in a small, manoeuvrable underwater vehicle—by this means direct viewing via a simple wide aperture lens is possible. It is not thought that a camera unit with a trainable lens can have anything but limited static application. It should be borne in mind that the periscope arrangement described by Mr. Gilbert whilst offering at first sight an ideal solution to "all round" viewing is attended by a number of disadvantages. The specially computed window must of necessity protrude beyond the casing and is vulnerable. The complete hemisphere is difficult to illuminate. There is a danger of damage to the target when an Image Orthicon is operated continuously in the vertical position. Mr. Gilbert has drawn attention to the restricted aperture of this system, which no doubt can be improved by the recalculation he suggests.

Mr. Ridgers suggests an interesting method of control which might be quite effective in some applications. Control in azimuth is a distinct advantage, as usually the angle of depression can remain fixed if objects lying on or just above the sea-bed are being viewed.

# of current interest . . .

Solar Energy Portable Radio

A portable radio receiver which is powered by solar energy has been demonstrated by an American Company in connection with the recent conference on the Uses of Solar Power. While the demonstration model was described as purely experimental, the Company indicated that it could become a commercial possibility if the cost of its battery could be reduced.

In discussing the device, the U.S. Industrial Correspondent of *The Financial Times* states that the battery is expensive because it is made of pure silicon, costing about $365 a pound. The solar powered radio contains seven silicon discs, each about one inch across, which become activated when exposed to the rays of the sun. They generate about 1½ volts, sufficient to operate the portable receiver which uses transistors.

The Company which made the battery for the receiver has also produced a 400-cell solar battery, which will generate 12 volts, and has been used to operate small motors. Yet another interesting development in this new field has been made by the Bell Telephone Laboratories, originators of the solar battery, who have installed a 432-cell battery to supply power to eight telephones in a rural area in the state of Georgia.

Microwave Harbour Beacon

A new, compact and inexpensive radar apparatus for guiding small fishing vessels into harbour when visibility is poor has been developed by the Admiralty Signal and Radar Establishment at Portsdown and is now about to be produced commercially.

The system is an adaption of the well-known Lorenz type of landing aid for aircraft and consists of a 3-cm radar type transmitter mounted at a harbour entrance and radiating from two aerials which have overlapping beams. The transmitter is so sited that the line of intersection of the two beams is along a safe course line for entering harbour. It uses a 7-kW peak power magnetron modulated by a 0·25-μ sec pulse at 1,000 p.p.s.

The output of the transmitter is switched in turn to each of the aerials in such a sequence that the morse letter B (— · · ·) is transmitted from one aerial and the morse letter V (· · · —) from the other aerial. The characters of one letter are transmitted during the period of the space intervals between the characters of the other letter so that along the line of intersection of the two beams, where the amplitude of the signals from each aerial is equal, a continuous signal is received. The effective angular width of this equi-signal sector is 1 deg.

The ship's receiver is a pre-tuned crystal receiver with a transistor amplifier coupled to a small horn aerial. The receiver and its power supplies are built around the horn, measure 4in. x 5in. x 5 in. and weigh 4½ lb. The power supplies are provided by a 4½ volt flashlamp battery. An improved model of the receiver is supported on a rotatable searchlight mounting. This is intended for fitting through the wheelhouse roof of a small boat. The output of this receiver is brought out to a 'phone jack on the rotating arm into which a loudspeaker attachment may be plugged.

The trials and demonstrations of the apparatus have been carried out at Fraserburgh and Arbroath and the equipment operated very satisfactorily out to a range of approximately seven miles from the harbour.

Science Graduates

In a written Parliamentary reply, the Financial Secretary to the Treasury states that the number of graduates in pure science is about 80,000. Nearly one-third are employed in teaching in schools, technical colleges and universities, and about one-eighth are in the public service, including the defence departments and the Atomic Energy Authority. About 3,000 young graduates are undertaking post-graduate research or instruction courses, and the balance are employed mainly in industry.

New B.S.I. Appointments

At the Annual General Meeting of the British Standards Institution, held on October 25th, Sir Roger Duncalfe was re-elected President of B.S.I. for a third year. Mr. John Ryan, C.B.E., M.C., was elected Vice-President on completion of his three-year period of service as Chairman of the General Council.

The new Chairman of the General Council is Sir Herbert Manzoni, C.B.E., who has been Engineer and Surveyor of the City of Birmingham since 1935. Sir Stanley Rawson succeeds Mr. S. J. Harley as Chairman of the B.S.I. Engineering Divisional Council.

A SURVEY OF WORK STUDY *

by

H. G. Wood, M.A., B.Sc. †

Based on a paper read before the North-Eastern Section in Newcastle-upon-Tyne in October 1954

SUMMARY

The basic analytical approach is introduced in terms of analysis, classification, critical examination and synthesis. Simple examples of method study are given and problems of work measurement and incentive schemes touched upon.

1. Introduction

Work Study is a subject which rather lacks a formal definition. Some people define it as Time Study, others as Production Study. The title "Work Study" is apt because it implies quite simply the study of work, but we are still not out of the wood, for "work" can have many definitions, from the "physical work" of the engineer, being force × distance, to the "life work" of the genius—the opus. Furthermore the subject is clouded by its own origins and by the abstruse nature of some of the aspects of it.

One thing is certain: the Work Study of today is a far bigger thing than the Time and Motion Study of twenty years ago. The problem today is not a question of how narrow shall be our definition of work—i.e. the old Motion Study approach of looking on the worker as a sort of machine, with his "work" approximating to the quantity (force × distance) of the physicists, but rather how broad shall we make the definition, i.e. what are the upper, rather than the lower, limits of the field of Work Study, covering as it does the whole range of shop activities, managerial procedures, design and research. It has long been said that Work Study is a "tool" of management, and that it certainly is—a very sharp tool, and one that has not always been wisely employed.

In the author's opinion, however, in modern development Work Study has gone beyond being a "tool" to become part of the "skill" of management, for certainly in essence Method Study is an attitude of mind or "a way of looking at things." This analytical attitude of mind can be successfully applied to any problem, managerial or otherwise, and goes far beyond the realm of Time and Motion Study.

We have therefore three, or possibly four natural sub-divisions of Work Study in its widest sense.

(*a*) A basic analytical approach, a mental attitude.

(*b*) The application of this to industrial work—method study.

(*c*) The quantitative analysis of human work—work measurement.

(*d*) The separate but associated subject of incentives.

2. The Basic Analytical Approach

Anything "new" is only new because, in our time, no one has thought of it before. Nevertheless, it pays to produce new things—new products, new toys, new books, new music, etc. In other words it pays to invent, but the invention itself soon becomes commonplace.

The invention is simply the answer to a problem, e.g. the windscreen wiper is the answer to the problem of keeping a windscreen free from rain.

How does the inventor invent? Usually by instinct—by a "flair," but, in addition, even unconsciously, the inventor analyses the problem. Likewise the "good manager" is "good" because he is able to analyse the problem in front of him, thereby focusing his mind on the real problem, which may not always be apparent.

It is suggested that there is a system whereby in a somewhat plodding fashion we can all do what the inventor does by instinct—see past the trees to the wood, analyse our activities, manual or mental into the productive and unproductive in terms of what we are really trying to do.

This may be explained by the analogy of chemical analysis. In Table 1 we see illustrated the system used by a chemist in analysis, in this

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† Industrial Consultant, formerly Chief Work Study Officer, British Productivity Council.
U.D.C. No. 621.004.1.

case a piece of chalk, the classification of his knowledge of the elements, his process of selection and synthesis, all to develop the new, and, for him, better product.

Similarly, in radio reception we have the analysis of the aerial signal into radio and audio frequency, the rejection of the former and the utilization of the latter. So you will see, for the sake of the argument, that, bizarre as it may seem, if we can invent an aerial which receives only audio frequency, then we have eliminated a rather complex and expensive bit of the receiver. Similarly, the production of beat frequencies in superheterodyne receivers is done by a combination process analogous to chemical combination.

In essence, therefore, the system of analysis, classification and selective synthesis is universal and not peculiar to the chemist. We can apply the same analytical examination to all our activities, mental or manual.

2.1. *Analysis*

There is the initial contrast of activity and inactivity, then the further analysis of activity into the actual "doing" of the job in mind, preparing to do it and "clearing up" after it is done. Finally, there is a "measurement" or "checking" operation to see that it is done to our satisfaction.

It is sometimes suggested that, in material operations at any rate, there is another activity called transportation, or moving things about, but strictly speaking transportation is simply a type of operation, usually a "make ready" or a "put away" but sometimes a "do", where the movement brings about the desired change.

So we have the *activities* analysed into:

(*a*) the "doing" operation, with further analysis into "make ready", "do" and "put away" activities;

(*b*) the "checking" or inspection; and

(*c*) the "transportation" in so far as it links the operations.

The *inactivities* may likewise be further analysed, and in industrial affairs it is usual to show them as "storage" which is deliberate and "delay" which is not.

2.2. *Classification*

Having considered analysis, what is our basis of classification? Obviously, the "operation" is "good", being what we are trying to do, inactivity is "bad", and checking or inspection is "indifferent", in so far as it is necessary in prevailing circumstances, but only so, because of the imperfection of the "operation." If the operation were perfect, we would not need to check. Furthermore the "do" operation is the key to the whole procedure.

2.3. *Critical Examination*

It is therefore logical, if not obvious, to challenge the key operation first, as, for example, in the case quoted earlier of the audio and radio frequency aerial signals, and it may be that when we look closely at the operation we find that even it is not what we are really trying to do, i.e. that we have been barking up the wrong tree, and must begin again.

In industrial work, for example, it is futile to improve on ancilliaries like transportation until the fundamentals of the job *as a whole* have been thoroughly examined in this way.

2.4. *Synthesis*

After analysis and critical examination the next stage is synthesis, the development of the new and better method.

If the problem is purely a material one, this is fairly easy, but if we are involved as human beings it is important to remember that the method must be acceptable.

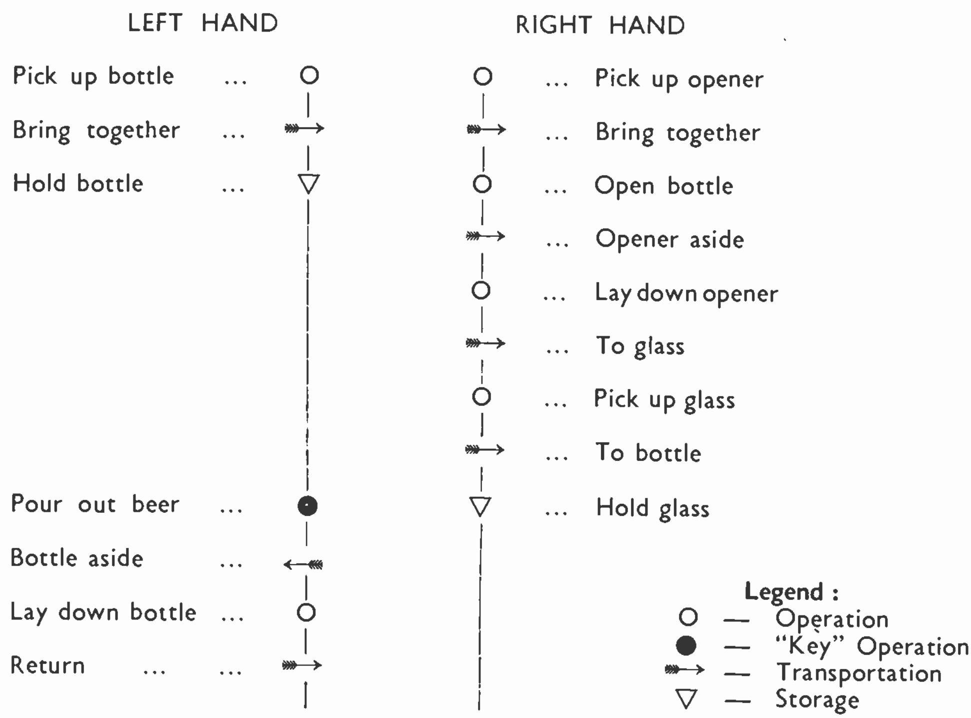
Table 1

An Analysis/Synthesis suggested from Chemistry

	"Conversion" Technique"			
"Old"	Analysis	Classification	Selective Synthesis	"New"
Old Product Chalk Ca CO_3	Calcium-Ca Carbon-C Oxygen-O	Metal Non-metal Gas	Eliminate C Combine Ca + O ⟶	New Product Quicklime Ca O

Table 2

An Analysis of the Actions associated in Pouring out a Glass of Beer



2.5. *Example of Analysis and Synthesis*

These various points can be illustrated by a very simple example—the homely job of pouring out a glass of beer. In Table 2 we see the activities of the operator (in this case his hands) analysed in this way. The key operation is "pour out beer" so logically we should query it first. What are we really trying to do? To transfer the beer from a narrow necked vessel to a wide-mouthed vessel. Why do it at all? Why not put the beer into a glass to start with? Thus we have jumped from Motion Study to Research. If we say "why drink beer at all?" we're in metaphysics, and if we go into fine analysis of finger movements etc. we are involved in Micromotion study, i.e. the same analytical approach can be used at *any* level.

Likewise the same job can have two aspects—one of self-service and one of service to others. If a bottle of beer is being opened for personal consumption it may be done in any way provided it does not annoy other people. If on the other hand for a barman serving others, there is need to be productive. To the publican with, say, five barmen, it will be obvious that whatever he thinks is the best method will have to be accepted by the barmen before he can expect real productivity.

This simple analytical approach is the basis of all Work Study. The ramifications downwards to such subjects as Micromotion Study, or upwards to Research are many and involved, but this is the basic formula, and as will be seen it is a mental "skill" rather than a "tool".

3. Method Study

In industrial Method Study there are many applications of the basic technique outlined above, exemplified by the different types of analytical charts used—e.g. the Operation Process Chart, the Flow Process Chart, the Man-Machine Chart, Right Hand–Left Hand Chart, down to the Chronocyclegraphs and

Simo Charts of Micromotion Study, but they are all merely different bases of analysis, some qualitative, some quantitative, some concerning themselves with a "strategical" or broad approach and some with a "tactical" or narrow sphere.

In the broad approach probably the most useful is the Flow Process Chart, as illustrated in Table 3, which is used to analyse and record the activities of the man or the machine, or in the passive sense, the changes in the material or workpiece.

(Note.—Some people use an arrow (➳) to denote Transportation, while others use a small "o".)

In the restricted field of one man and his job, probably the most useful are the Right Hand–Left Hand Chart, as in Table 2, or the Man-Machine Chart which is similar, but provides a quantitative balance, in terms of time, between the activities of the man and those of the machine.

In all cases the basic process is the same, analysis and classification followed by a synthesis of the new method, and in synthesis, of course, it is essential to consider all facts, material and human, in deciding on the new improved method.

One or two personal examples may be of value.

Example 1—the "broad" approach—a Study in a Bath Foundry. (Process Flow Chart.)

The firm concerned wished to mechanize their foundry and decided to do some Method Study at the design stage.

The first challenge was the whole business. Why make the baths at all? Would showers be better? etc. We still decided on baths, but the value of the "leading question" will be seen in so far as the man who goes one better than baths will be on to a good proposition.

Table 3

Flow Process Chart

SUMMARY		Present	Proposed	Difference
Operations	O			
Transportations	o			
Storages	▽			
Inspections	□			
Total Details				
Total Distance				
Total Time				

Job ....

....

Subject Charted ....

Date .... Charted by ....

DETAILED DESCRIPTION Present Proposed	Quality	Symbol	Distance	Time	Reason	NOTES 1. Eliminate. 2. Combine. 3. Change seq. 4. Simplify.	
1.		O o ▽ □					
2.		O o ▽ □					
3.		O o ▽ □					
4.		O o ▽ □					
5.		O o ▽ □					
6.		O o ▽ □					

When we analysed the present method, however, we found far more "make ready" and "put away" work than actual "doing", i.e. casting of the baths—they seemed quite out of proportion, and the explanation was the use of cast iron. This was in turn queried and alternative materials such as steel considered and rejected. It did seem however, that plastics might prove a good material and indeed it has done. (This study was done three years ago.)

Finally, by applying the same analytical approach to each section of the job, a new and highly efficient lay-out was prepared.

(It should be noted that the importance of the interplay of the non-technical work study technique and the technical "know how" of the process cannot be over-stressed. The function of Work Study is to ask the stupid questions, but obviously intelligent answers must be forthcoming, either from the Work Study men themselves, or as in the present case, from the technical people concerned.)

Example 2.—The Beer Bottle (Right Hand–Left Hand Chart).

In a serious study of the light-hearted example already quoted, two new ideas have emerged which are being developed—a combined bottle-glass and a self-opening bottle—the "opener" is attached to the crown-cork rather like the "tag" on a motor lubricating-oil bottle.

Example 3.—The Spot-Weld Problem (Man-Machine Chart).

This little company had only two spot-welding machines and wished to increase output without further capital expenditure. A Man-Machine analysis showed how this could be done by employing an extra man.

The actual charts associated with these examples cannot, unfortunately, be published as they are the property of the individuals concerned.

From the above examples it will be seen that the scope of Method Study is immense. On the other hand, it will also be seen that there is nothing really new about it, at any rate, to the knowledgeable. It is however, an excellent wit-sharpening technique which can be applied by anyone. In essence it does not require pencil and paper and complicated charts, etc. These only enter in when the subject under consideration is itself complicated. The author knows of one large company which is getting astounding results from letting everyone in the organization make suggestions and making it worth their while by making substantial awards for any that are worthwhile.

4. Work Measurement

Lord Kelvin said that to put numbers to a problem was to half-solve it. Certainly, reverting to the chemist, his analysis is incomplete if only qualitative—to get a full picture he must know "how much" as well as "what sort."

Likewise in radio it is helpful but inconclusive if we know merely that there is a current or a potential somewhere. Our knowledge only becomes really useful when we know "how much."

Similarly in management, when we are trying to co-ordinate or balance up the activities of men and machines it becomes essential to measure the activities quantitatively as well as analyse them qualitatively in the manner described above.

Hence the need for Work Measurement. The problem is the determination of the standard or yard-stick. In the case of a machine it is fairly easy to establish such standards because of our ever-growing knowledge of machines and their capabilities, e.g. most car manufacturers specify a cruising speed for their cars, which is usually rather more than half the maximum speed, and which can be kept up indefinitely if the vehicle is given proper fuelling, care and maintenance.

The basic problem in assessing human work standards is that if our knowledge of machines is still empirical, how much more so is our knowledge of ourselves.

It is an easy thing to determine a *given* rate of working, just as it is to determine a given speed for a vehicle, but the relation of that, namely "what is" to "what ought to be", is a very difficult task indeed.

Even looking on man as a machine, which he is not, it is impossible to assess the various factors influencing his work capacity, such as fatigue, with anything like the accuracy of our measurements of real machines.

Add to that the fact that in our democratic society the community determines its own standards which are not necessarily even static, and you will see the extreme difficulty of the task.

Nevertheless, it is a job to be done, and a job which can be done, and is being done successfully—but on the basis on which all such jobs must be tackled, namely the exercise of human judgment.

Judgment is used in two stages—one difficult and one fairly easy.

The difficult part is the determination of acceptable standards. This is done on a basis of factual knowledge acquired either through long experience or by the collection of sufficient representative data, by statistical or other means.

The easier part is the relationship of any given performance to this standard—the process known as Performance Rating, although frequently this term implies the combination of both the determination of the absolute value and the relating to it of the observed value.

4.1. *Basic Procedure*

In actual practice, the job of determining a Work Standard is usually done in four steps, as follows:—

(*a*) Timing a given rate of working.

(*b*) Relating this performance to the concept of normal, i.e. Performance Rating.

(*c*) Allowing for the effect of fatigue.

(*d*) Allowing for other factors.

As we are concerned with the rates of activity, time must always enter in and be measured, but not necessarily by a stop-watch. The stop-watch is the "micrometer" of time measurement and should be used as such—when appropriate. If the time units are large, say hours, there is no point in using a stop-watch. On the other hand there are occasions when even the stop-watch is too "coarse" and a finer gauge is necessary, such as a film giving divisions of 1/16th of a second, or electronic counters and the like. (The idea of "coarse" and "fine" is entirely relative: nuclear physicists are now working in units of 1/10,000th sec.)

The stop-watch is in common use for two reasons: (*a*) It is suitable for most types of repetitive job, and (*b*) even so-called "long jobs" and "one off's" can usually be broken down into short elements.

4.2. *Modern Developments*

This elemental breakdown, similar to that of the chemist, leads to a new and logical development—the use of standard elemental time data to compile time values for jobs of the same class, built from the same types of element, though in different permutations and combinations.

The principle is simply the same as that used in, say, radio or car assembly, with different groupings of various standard components producing a variety of finished products.

These "synthetics" as they are sometimes called, are often criticized on the suggestion that they are "ersatz", and certainly if they are used inappropriately they may produce doubtful results. On the other hand, if they are accurately computed from reliable local data they give remarkably good results and have two big advantages, namely economy of production and uniformity. They are, however, only worth while if a large number of similar time standards are required, for, of course, the initial process of compilation is liable to be lengthy and expensive.

As stated, synthetics or standard data are absolutely logical, just as chemical elements are logical bases for synthesis of new products. Furthermore, just as in recent times the elements of the chemist have been further analysed by the atomic physicists, so have the "elements" of the Time Study men been further analysed by the exponents of what are known as predetermined motion times.

For example, where the "element" of Time Study might be "Insert paper into typewriter", the predetermined motion time people analyse this into a series of arm and finger movements etc., so that, as far as manual work goes at any rate, they hope to be able to establish a "common denominator" to all work in this way.

The idea is useful as long as we remember the one big difference between chemical analysis and work analysis—material things are the same the world over, but human standards are not, i.e. the coat must be tailormade, so that any such "universal" standards may require modification to suit local conditions.

5. Incentives

Incentive schemes are simply a means of "sharing out the cake"—of giving a reward for work done. There are many other ways of doing this—by high base wages, production bonuses, suggestion schemes, profit-sharing etc., and it is not in the scope of this paper to enlarge on these except to say two things:

(*a*) Some combination of the above will probably give the best over-all results.

(*b*) Incentives are only mentioned at all here because, while quite an independent subject, it has been found in managerial experience that if we wish to base reward on human work accomplished (it can also be based on many other things) we must have a measure of that work—i.e. Work Measurement.

The basis of all incentive schemes is two-fold:—

(*a*) To establish a "norm" beyond which incentive payment is made and,

(*b*) To determine the fair and equitable rate of payment for production beyond this norm.

In general the norm will be that of Work Measurement—i.e. the "cruising speed", although this is sometimes reduced, as for juveniles, old people, and learners.

The rate of incentive pay can again vary. In manual work it is customary today to pay on a straight-proportional basis, i.e. the over-production is paid for at the same rate as the basic norm or quota, but where other factors enter in the rate of incentive payment may be higher or lower than straight proportional.

If, for example, the over-production makes sizeable savings in overheads, as when expensive machinery is used, it may be not only fair, but shrewd, to pay back some of these savings to the workers on a greater than straight proportional basis, while on the other hand, if quality is all-important, or craft skills have to be safeguarded, then the law of diminishing returns may meet the case.

It can thus be seen that incentive schemes are a subject in themselves, and this small section has been added simply to show the relationship of Work Measurement and incentives.

As has been stated, there are many ways of "sharing the cake" and motivating people to give of their best, and valuable as incentive schemes are, there is growing evidence that the *suggestion* schemes, mentioned under Method Study, enlisting as they do the operative's intellect as well as his body, may contribute at least as much as incentives to greater productivity.

6. Conclusions

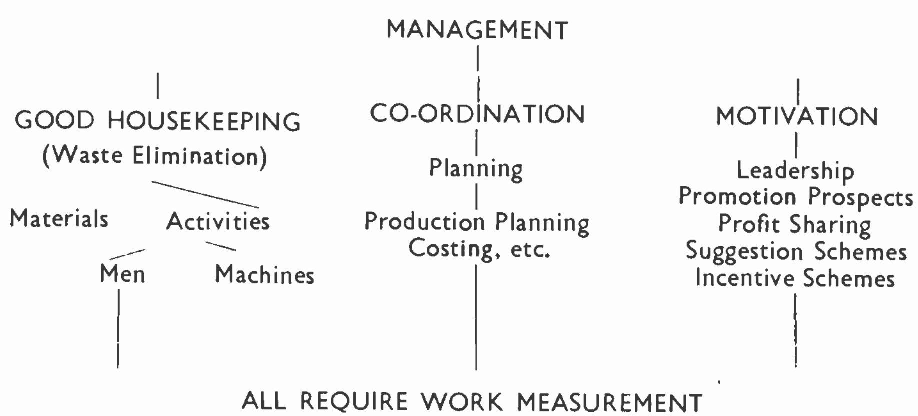
The whole subject of work study is summed up diagramatically in Table 4, showing three managerial functions of Good Housekeeping, Coordination and Motivation.

Remembering that the basic analytical attitude of mind is a "skill" of management, which therefore pervades all managerial function, we see Method Study fitting in as a "line" function of management under Good Housekeeping (or Waste Elimination) whereas Work Measurement appears as a staff or advisory function supplying data to all three functions.

It is interesting also to note that the need for accuracy in Work Measurement rises as we move from left to right on the diagram. Rather rough and ready Work Measurement will serve for Method Study purposes, and no great harm will be done if it is somewhat inaccurate.

More accurate data are required for production planning, costing, etc., and very accurate data are required as a basis for successful incentive schemes.

Table 4



. . . Radio Engineering Overseas

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

538:621.385.029.64/5

Permanent magnets for electronic tubes used at s.h.f. M. DE BENNETOT, *Onde Electrique*, **35**, pp. 747-763, August-September 1955.

Considers the theoretical and practical aspects of the designs for magnetrons, travelling wave tubes and backward wave tubes.

621.37/9:629.13

The problem of aircraft components.—M. HERVE, *Onde Electrique*, **35**, pp. 645-654, July 1955.

A study of the various specialized components (resistors, potentiometers, capacitors, transistors) which must be miniature and adapted to tropical conditions. Such components will later find a much wider use than the field of aviation.

621.374

Frequency of coincidence of two sets of recurrent pulses.—H. RAKSHIT and S. C. MUKHERJEE. *J.Instn Telecom. Engrs*, **1**, pp. 130-135, September 1955.

The recurrence frequency of coincidence of two sets of pulses is described. It is shown that when the pulses are very narrow the frequency of coincidence is irregular, but when the pulses are broad the irregularity vanishes if the two frequencies do not differ widely. Coincidence is then found to occur in groups, the number of each group depending on the width of the broad pulses. The number of groups of coincidence is further found to correspond to the difference between the frequencies of the two sets of pulses. When the two frequencies are not very close but a harmonic of one is close to a harmonic of another, coincidence may again occur in groups if these harmonics are not of high order. The group frequency is different from the difference between the frequencies of the two harmonics. The application of this principle of pulse coincidence to measurement of pulse recurrence frequency is finally discussed.

621.376.5

On the calculation of the spectrum of modulated pulse trains.—M. SANCHEZ and F. POPERT. *Archiv der Elektrischen Ubertragung*, **9**, pp. 441-452, October 1955.

To derive the frequency spectra of time-modulated periodic pulse trains such as are encountered in pulse-modulated multi-channel systems, use is made of a model concept first devised by W. R. Bennett. This model allows, among other things, a lucid interpretation of the fact that a time-modulated pulse train is a doubly-periodic function resulting from a "scanning function" and a "modulating function." The adaptation of the method to an exact calculation of the spectra of the principal time-modulated pulse trains encountered in practice is shown, using for simplicity a sinusoidal modulating function (single-tone modulation) as a basis. The formulae found are evaluated numerically and plotted for a particular case. Referring to the multi-tone problem, the "signal-to-noise ratios" of the spectrum components falling in the transmitted frequency band are then stated for the case of a pulse train modulated with a continuous single tone.

621.385.032.216

Cathodes of sintered alkali-earth oxides containing zirconium.—G. MESNARD and R. UZAN. *Le Vide*. **10**, pp. 124-134, July-September 1955.

The influence of an addition of zirconium powder to the mixtures of powdered barium and strontium carbonates and nickel or tungsten employed in the preparation of cathodes by pressing and sintering is considered. It is pointed out that the most interesting results are obtained by sintering in vacuum; thermionic properties of these cathodes are studied, distinguishing between cathodes containing small and large proportions of zirconium. The evolution of activation and performances are specified for the different cases.

621.392.2

Transmission of waves on a dielectric tube.—H.-G. UNGER. *Fernmeldetechnische Zeitschrift*, **8**, pp. 438-443, August 1955.

The results of a theoretical investigation of the wave propagation along dielectric tubes are reported. The responses of the wavelength, the attenuation and the field diameter (which is a measure for the extension of the field into outer space) as a function of the tube dimensions and the frequency, are shown for the case of the three lowest modes, E_{01}, H_{01}, and HE_{11} and for various values of the dielectric constant of the tube material. The HE_{11}-mode is most suitable for the application of the dielectric tube as a low-loss waveguide.

621.396.029.51

Low-frequency radio communications and engineering.—R. S. THAIN. *Journal of the Engineering Institute of Canada*, **38**, pp. 1373-1378, October 1955.

Discusses the present role of the low frequencies (70-200 kc/s) in radio communication in Canada, summarizes the present state of knowledge of the propagation of these radio frequencies, and outlines briefly some of the engineering problems encountered in systems design.

621.396.11

Electronic collisional frequency in the F-region over Calcutta.—S. DATTA. *Indian Journal of Physics*, **38**, pp. 279-284, June 1955.

The measurements relate the reflection coefficient of an ionospheric region with the difference between the group and optical paths within the region. The collisional frequency is found to be of the order $3{\cdot}8 \times 10^3$ per sec. per electron in the F-region of the ionosphere. An attempt is also made to find out the variation of the same with height in the F-region.

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GRADUATESHIP EXAMINATION—PART I

PHYSICS

18th May, 1955 — 2.30–5.30 p.m.

Candidates are required to answer SIX questions only of which not more than THREE may be taken from one section.

Sections A and B MUST *be answered in separate books.*

Velocity of sound in air to be taken as 33,000 cm/sec
J = 4·2 Joules/cal.

SECTION A (Heat, Light and Sound)

1.

Describe how you would determine the specific heat of a metal using a calorimeter. Outline clearly the sources of error and the precautions you would observe to minimise them.

The temperatures of equal masses of three different liquids (*not chemically reactive*), P, Q, R, are 10° C, 20° C and 30° C respectively. On mixing P and Q in a calorimeter the temperature of the mixture is 16° C, on mixing Q and R, 27° C. What would be the resulting temperature if P and R were mixed?

2.

(*a*) Provided with a sonometer and tuning forks of known frequency, explain fully how you could determine the density of the material of the sonometer wire.

(*b*) A cylindrical diving bell of height 5 ft. is lowered to the bottom of a river. The atmospheric pressure is equivalent to 32 ft. of water. The water rises 1 ft. inside the bell. What is the depth of the river? (*Assume no temperature change.*)

3.

(*a*) Derive an expression relating the object distance, image distance and radius of curvature for a concave mirror.

(*b*) A concave mirror has a focal length of 6 cm. How far from it must an eye be placed to see an image of itself enlarged 3 times, and where is this image formed?

4.

(*a*) A lens is made of glass of refractive index 1·5, and has a focal length of 10 cm. What is its focal length when immersed in a liquid of refractive index 1·35?

(*b*) A man fires a rifle between two parallel cliffs; he hears echoes after 1, 3 and 4 seconds. Explain this and calculate the distance the cliffs are apart.

(*c*) A train has a mass of 250 metric tons and is travelling at 40 km.p.h., the brakes are applied to reduce the speed to 25 km.p.h. Find the heat generated by the brakes assuming that all the work done is converted into heat. (*1 metric ton = 1,000 kilograms.*)

5.

(*a*) The focal length of a thin double convex lens is 40 cm, and it is made of glass of refractive index 1·5. Find the radius of the second surface if that of the first is 25 cm.

5. *(contd.)*

(*b*) A 400 c.p.s. tuning fork is held close to the open end of a cylindrical tube of radius 2·5 cm which is closed at its other end. What length of tube will cause the loudest sound to be produced.

(*c*) What fraction of the mass of water vapour in the air would condense if the temperature fell from 20° C to 5° C, the relative humidity being originally 60% at 20° C. (*Saturation pressure of water vapour at 20° C = 17·5 mm, at 5° C = 6·5 mm.*)

SECTION B (Magnetism and Electricity)

6.

Describe how you would compare the magnetic moments of two similarly shaped magnets *either* (*a*) by using a deflection magnetometer, *or* (*b*) by a vibration method.

A magnet of moment 80 c.g.s. units is suspended in the magnetic meridian. What couple is required to hold the magnet at 40° to the field? (*H = 0·18 gauss.*)

7.

What factors affect the capacitance of a parallel plate capacitor?

A capacitor of capacitance 10 μF is charged to a potential difference of 50 V. A capacitor (uncharged) of 5 μF is connected across it. Calculate (*a*) the potential difference across the combination, (*b*) the energy lost on connection.

8.

(*a*) Distinguish between electro-motive force and potential difference of a battery. How would you measure the internal resistance of a cell?

(*b*) Prove that a source of e.m.f. delivers maximum power to an external circuit when this circuit has a resistance equal to that of the internal resistance of the source.

9.

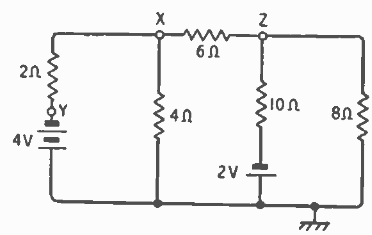
(*a*) State Kirchoff's Laws.

(*b*) In the circuit shown calculate:

(i) power dissipated in the 6 ohm resistor.

(ii) p.d. across XY.

(iii) potential of point Z.



10.

(*a*) A coil of self inductance 3 henries carries a steady current of 0·5 amperes. Calculate the number of flux linkages. What e.m.f. is induced across the coil when the current is (i) halved, (ii) doubled both in 0·1 seconds.

(*b*) A resistive heating element in a kettle brings 1 litre of water to the boil from 10° C in 10 minutes. If the mains voltage is 200 V and it is assumed that all the heat generated is used in heating the water, calculate the resistance of the heating element.

(*c*) A wire of length 25 cm is in a magnetic field of 500 lines. Calculate the magnitude and direction of the force exerted on the wire when it carries a current of 2 amperes if the wire is at right angles to the field. What is the force exerted if the wire lies along the field?

The British Institution of Radio Engineers

(Founded in 1925. Incorporated in 1932.)

GRADUATESHIP EXAMINATION—PART II

PRINCIPLES OF RADIO ENGINEERING

19th May, 1955 — 10 a.m.–1 p.m.

Candidates are required to answer SIX questions only

1.

A triode with the following static characteristics is connected to a load resistance of 15 kΩ :

	V_a (volts)	50	80	100	120	140	160
I_a (mA)	$V_g = -2$V	1	3	5	7	10	
	$V_g = -4$V		0·5	1·5	3	5	7·5
	$V_g = -6$V				0·75	1·75	

(*a*) If the grid bias is set at -4 V with an h.t. supply of 150 V, find the operating point on the static characteristic.

(*b*) Under these conditions, what is the average a.c. power fed to the load impedance when a sine wave of 2 volts maximum amplitude is applied to the grid ?

2.

(*a*) Describe the construction of a moving coil meter and explain the principles of operation.

(*b*) A moving coil instrument has a resistance of 20 Ω with a full-scale deflection of 1 mA. Show how it can be adapted to read 1000 V.

(*c*) What would be the percentage error if this voltmeter was used to measure the anode to cathode voltage of a triode valve having a 300-volt h.t. supply, an anode resistor of 100 kΩ and an anode current of 1 mA? Assume that the anode current is proportional to the anode volts.

3.

A voltage of r.m.s. value 2 V, with a frequency of 1000 c/s, is applied to a coil having a resistance of 50 Ω and an inductance of 8 mH. Find an expression for the current in the circuit and calculate the power supplied.

What value of parallel capacitance is required to bring the current in phase with the voltage ?

4.

(*a*) What do you understand by the " time constant " of a series RC circuit ?

(*b*) Sketch the voltage wave shape across the resistor when a voltage square wave of form shown in Fig. 1 is applied across this circuit.

(*a*) When T is much greater than CR.

(*b*) When T is equal to CR.

(*c*) When T is much less than CR.

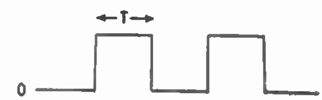


Fig. 1

(*c*) Determine the frequency with which the neon flashes when it glows at 150 V and is extinguished at 125 V (Fig. 2.) Neglect the tube resistance when the tube is conducting.

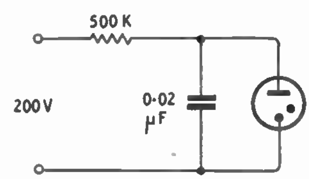


Fig. 2

5.

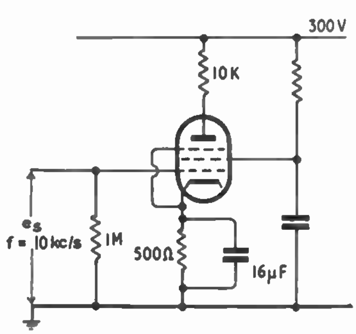


Fig. 3

The valve in the circuit (Fig. 3) has the following characteristics :

$-V_g$	0	1	2	3	4	5	6	(volts)
I_k	17	15	12	8	4	2	1	(mA)

What is the value of the grid bias voltage ?

State the approximate gain of the stage and justify any assumptions made.

What would be the effect of removing the bias capacitor ?

6.

Describe the main features of wave propagation in the v.h.f. band and discuss the advantages of this band for certain types of communications.

7.

State Thé·'enins Theorem.

Show l.ow a π-network can be transformed to an equivalent T-network.

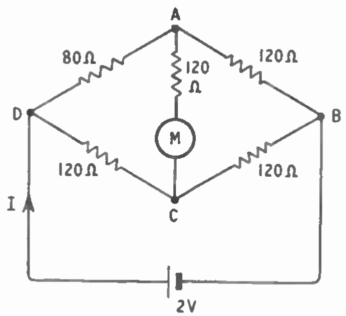


Fig. 4

For the circuit (Fig. 4).

Find (*a*) The current in the meter.

(*b*) The current supplied by the battery.

8.

Derive an expression for the effective primary impedance of the circuit (Fig. 5).

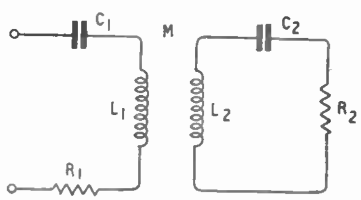


Fig. 5

$C_1 = 0{\cdot}05\,\mu F.$
$C_2 = 0{\cdot}1\ \ \mu F.$
$L_1 = 2$ mH.
$L_2 = 1$ mH.
$M\ = 600\ \mu H.$
$R_1 = 20\Omega.$
$R_2 = 12\Omega.$

If the components have the above values and a voltage of 10 V at a frequency of $\frac{10^5}{2\pi}$ is applied to the terminals, find the effective primary resistance and reactance, also the secondary current.

9.

Describe TWO of the following and deduce an expression in each case to explain the principles of operation.

(*a*) A tuned anode oscillator.

(*b*) A frequency changer.

(*c*) An amplitude modulated wave.

10.

An inductive resistor is connected in parallel with a capacitor across a variable frequency oscillator. Derive an expression for the frequency at which the supply current is in phase with the alternator voltage. Draw the vector diagram for this condition and also obtain an expression for the impedance of the circuit at this frequency.

The British Institution of Radio Engineers

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GRADUATESHIP EXAMINATION—PART IIIa

MATHEMATICS

19th May, 1955 — 2.30–5.30 p.m.

Candidates are required to answer SIX questions only

1.

(*a*) The following results were obtained in testing the voltage-current response of a certain circuit :—

V	79·4	141	224	316	400
I	3·55	7·4	13·5	20·9	28·2

Show by drawing a suitable graph that V and I may be related by the equation $I = kV^n$ and determine the values of k and n.

(*b*) Deduce the condition for the quadratic equation $Lx^2 + Rx + \frac{1}{C} = 0$ to have complex roots. Determine the roots and express them in the form $a + jb$ when $L = 0{\cdot}02$, $R = 40$ and $C = 10^{-5}$.

2

(*a*) State the Binomial Theorem and write down in the simplest form the fourth term of $(2x - 3y)^7$ and the sixth term of $\left(\frac{1}{3} + \frac{2}{y}\right)^9$

(*b*) If a sum of money is invested at compound interest, show that the amount at the end of any year is a term in a geometric progression. Calculate the amount at the end of ten years when £100 is invested at 4% per annum (i) if the interest is added yearly ; (ii) if the interest is added half-yearly.

3.

(*a*) Solve the equation $21^x = 5^x(2^{2x+1})$ given that $\log 2 = 0{\cdot}301$, $\log 3 = 0{\cdot}477$ and $\log 7 = 0{\cdot}845$.

(*b*) By introducing a subsidiary angle solve, from first principles, the equation

$$6 \cos x + 8 \sin x = 9.$$

4.

(*a*) The characteristic impedance Z of a transmission line is given by $Z^2 = \dfrac{R + j\omega L}{G + j\omega C}$.

Determine the condition for which Z is a real quantity.

(*b*) In a two-stage amplifier the gain of the first stage is $\dfrac{-195}{12 + 5j}$ and that of the second is $\dfrac{-500}{24 - 7j}$.

Calculate the magnitude of the overall gain and the phase shift.

5.

(*a*) If z is a function of x and y is a function of z, explain how to obtain the differential coefficient of y with respect to x.

(*b*) If $3x^2 + 4y^2 + 2x + 6y = 10$ find the value of $\frac{dy}{dx}$.

(*c*) Differentiate with respect to x:—

(i) $\log_e \frac{1 - \cos x}{1 + \cos x}$ (ii) $e^{ax} \cosh bx$

6.

Determine the limiting values when $x = 0$ of the following expressions :—

(i) $\frac{1 - \cos x}{x^2}$ (ii) $\frac{x - \sin x \, . \cos x}{x^3}$ (iii) $\frac{\cosh x - \cos x}{x \sin x}$

Find also the limit when $x = 1$ of $\frac{4x^3 - 5x^2 + 1}{2x^5 + 3x^3 - 5}$

7.

Integrate with respect to x the following expressions :—

(i) $3 \sin (2x + 3) + 2 \cos (4 - 5x)$ (ii) $e^{4x} - 3x^2$

(iii) $\frac{6x^2}{1 + x^3}$ (iv) $\frac{3}{x \log x}$

Evaluate also the integral $\int_2^3 (x - 3)(x + 2) \, dx$

8.

Deduce from first principles an expression for the area under a curve between given limits.

Calculate the area enclosed between the curves $y = 1 + x^3$ and $y = x^2$ within the limits of $x = 0$ and $x = 2$.

9.

Show that the equation

$$\frac{d^2v}{dt^2} + m\frac{dv}{dt} + nv = 0.$$

may be satisfied by the expression

$$v = ke^{bt} \sin pt$$

and determine the value of m in terms of b and of n in terms of b and p.

The British Institution of Radio Engineers

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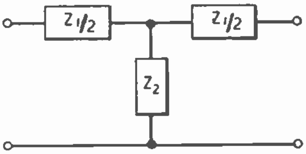
GRADUATESHIP EXAMINATION—PART IIIb

ADVANCED RADIO ENGINEERING

20th May, 1955 — 10 a.m.–1 p.m.

Candidates are required to answer FIVE questions only



The symmetrical T section filter shown in the figure is terminated in its characteristic impedance. Show, from first principles, that its transmission constant γ is given by :—

$$\gamma = 2 \log_e \left(\sqrt{1 + \frac{Z_1}{4Z_2}} + \sqrt{\frac{Z_1}{4Z_2}} \right)$$

Design a T type constant-k low-pass filter to have a cut-off frequency of 796 cycles per second and a terminal impedance of 600 ohms.

2.

An aerial array consists of N vertical aerials in a straight line, each being the same height above the ground and the separation between adjacent radiators being d. They are all fed in phase with currents of the same magnitude, the wavelength of the resulting radiation being λ. P is a distant point in the same horizontal plane as the aerial centres and lies on a line making an angle θ to the normal to the array.

$$\text{Prove that } E = E_1 \sin \frac{N\alpha}{2} \Big/ \sin \frac{\alpha}{2}$$

where E is the total field at P, E_1 is the field at P due to a single aerial and $\alpha = \dfrac{2\pi d}{\lambda} \sin \theta$.

Such a four-element broadside array has half wave spacing between the elements which carry equal currents fed in phase. Calculate the positions of the maxima and minima of the intensity pattern in a horizontal plane, and illustrate your answer with a sketch.

3.

Derive an expression for the gain of a resistance-capacitance coupled amplifier at low, mid-band and high frequencies. Hence derive an expression for the gain-bandwidth product for the case of an RC coupled pentode amplifier. Discuss the significance of your result.

4.

Derive expressions for the gain and input admittance of a cathode follower stage.

A triode has a mutual conductance of 3 mA/volt and an anode slope resistance of 10 kΩ, the anode-grid capacitance being 4·0 pF and the grid-cathode capacitance 3·5 pF. If the valve is used as a cathode follower with a resistance load of 60 kΩ and a grid leak of 200 kΩ, calculate the gain, input capacitance and input admittance at a frequency of 2 Mc/s.

5.

Discuss in detail the design of a class C amplifier.

A valve used as a class C amplifier has an anode supply voltage of 10,000 volts and the instantaneous anode potential is 1500 volts when the maximum grid potential is 300 volts positive. If the amplification factor of the valve is 50, and the angle of flow of the anode current is 140°, calculate the grid bias voltage required. Prove any formula you use.

6.

Draw the circuit of a diode detector suitable for use in a superheterodyne receiver having an intermediate frequency of 465 kc/s. Give circuit component values and justify your choice. Show how automatic volume control may be obtained in such a receiver.

If the load of a detector may be represented by a resistor R shunted by a capacitor C, show that to enable the d.c. voltage across C to follow the envelope of an a.f. modulated r.f. carrier:—

$$\frac{1}{2\pi fCR} \geqslant \frac{m}{\sqrt{(1-m^2)}}$$

where f is the a.f. modulating frequency and m is the modulation factor.

7.

Draw the circuit of a multivibrator and explain briefly the mechanism by which oscillations occur.

A double triode is used as a multivibrator, each anode load being 40 kΩ, each grid leak being 200 kΩ, and each coupling capacitor having a capacitance of 0·1 μF. If each section of the valve has a d.c. resistance of 10 kΩ when it is conducting and the amplification factor of each is 20, calculate the approximate frequency of the resulting oscillation. Derive the formula you use.

8.

Draw the circuit and explain the action of a Q-meter.

Describe a method of using the Q-meter to measure the characteristic impedance of a transmission line, giving the detailed theory of each individual measurement made. Explain the precautions necessary to ensure accuracy.

9.

Discuss the relative merits of amplitude modulation and frequency modulation in the transmission of intelligence.

Draw the circuit and describe the action of a Foster-Seeley discriminator.

The British Institution of Radio Engineers

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GRADUATESHIP EXAMINATION—PART IV

RADIO RECEPTION

20th May, 1955 — 2.30–5.30 p.m.

Candidates are required to answer FIVE questions only

1.

An untuned loop aerial consists of 4 turns of wire, has a diameter of 30 cm and inductance 10 μH. It is inductively coupled to the first tuned circuit of a receiver, the coupling inductance being 5 μH and the coupling factor 0·5. If a capacitance of 400 pF is to tune the circuit to resonance at a frequency of 150 kc/s, calculate : (*a*) The secondary inductance, (*b*) The field strength required to produce a signal of 10 μV across the tuning capacitor. The Q-factor of the aerial and both inductors is 50.

2.

A pentode i.f. amplifier has a tuned transformer as an anode load. The transformer has identical primary and secondary circuits of Q = 50 and coupling factor 0·025 between primary and secondary. The circuits are tuned to 450 kc/s.

Calculate, for a signal of 450 kc/s modulated at 4·5 kc/s the attenuation of the sidebands measured in dB referred to the carrier output level.

3.

Describe how the power supplies for a receiver may be obtained from a 12 V accumulator with the aid of a vibrator. What problems are peculiar to this type of supply, and how may they be overcome ?

4.

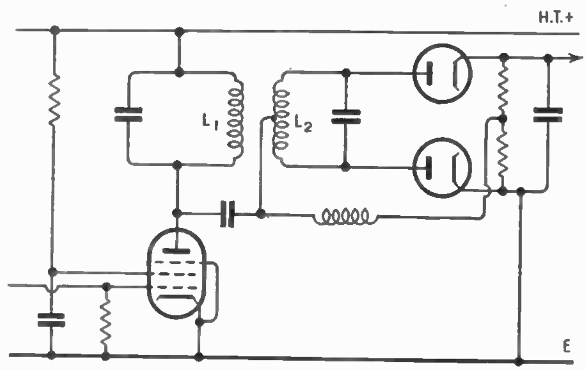
(*a*) Discuss the effect of applying a delay bias to the a.g.c. detector diode of a receiver.

(*b*) Delayed a.g.c. operates on the frequency changer and i.f. amplifier of a receiver. The gain of the frequency changer drops by 2·5 dB/volt bias and that of the i.f. amplifier by 1·25 dB/volt. The a.g.c. is to operate on a signal input of 50 μV to the receiver and an increase of input to 2 mV is to raise the output by 10 dB. The a.g.c. detector efficiency is 90 per cent. Calculate the delay on the a.g.c. diode.

5.

A diode detector is to operate without distortion at modulation factors of up to 0·8 at 5 kc/s. If the maximum permissible resistor between grid and cathode of the following a.f. amplifier stage is 1 MΩ, calculate the component values of the RC combination comprising the diode load. The detector efficiency is 95%. Derive any formulae and state any assumptions made.

6.



In the phase discriminator shown, $L_1 = 5\ \mu H$, $L_2 = 8\ \mu H$. The coupling factor between L_1 and L_2 is 0·05 and the Q factor of each circuit is 40. The resonant frequency of each circuit is 10 Mc/s, the pentode has $g_m = 2$ mA/V and the detector efficiency is 95%.

Calculate the p.d. across the diode load when a signal of 1 V r.m.s. is applied to the grid of the pentode at 10 kc/s from the resonant frequency. Justify any approximations and formulae used.

7.

Discuss the conditions controlling the maximum frequency at which conventional r.f. amplifier valves and circuits may be used.

8.

(*a*) Discuss the features of the design of an output transformer for a push-pull power amplifier.

(*b*) The anode to anode load of a push-pull amplifier is to be 10 kΩ, and it is to feed a 5Ω load. The transformer has 8000 primary turns and is to have not more than 2 dB drop in output at 20 c/s. The transformer laminations have an area of 55 cm², thickness 0·5 mm and mean length of iron path 25 cm. The incremental permeability is 900. Calculate the number of secondary turns and the number of laminations to be used in the transformer construction.

9.

Derive an expression for the polar diagram, in the plane of the aerial, of an isolated straight aerial of length $k\lambda$ fed at one end and terminated at the other by its characteristic impedance. Neglect attenuation along the aerial.

Sketch the polar diagram for the case where $k = 1$. Compare this type of aerial with the resonant type.

The British Institution of Radio Engineers

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GRADUATESHIP EXAMINATION—PART IV

RADIO TRANSMISSION

20th May, 1955 — 2.30 - 5.30 p.m.

Candidates are required to answer FIVE questions only

1.

(*a*) What are the advantages and disadvantages of beam tetrode and earthed grid triode amplifiers for use in the r.f. amplifier stages of a transmitter?

(*b*) Calculate the input impedance of an earthed grid amplifier in which the anode load is a pure resistance *R*, the valve parameters being μ, g_m and r_a.

2.

(*a*) Give a brief description of a ground mobile or airborne radio transmitter capable of operation on a large number of crystal-controlled frequencies and explain how the desired channel is selected.

(*b*) A pentode valve of mutual conductance g_m has an anode load consisting of an inductance *L* of resistance *R* shunted by a capacitance *C*. Calculate the voltage gain at resonance and the bandwidth between the two points where the gain is 6 dB down on the maximum.

3.

(*a*) Draw a block diagram of an independent sideband transmitter with the necessary terminal equipment for sending telephony over one channel and voice-frequency telegraph signals over the other. Give a technical description of the channelling equipment.

(*b*) Explain what is meant by cross-modulation and state what practical measures can be taken in the design of r.f. amplifiers to minimise this form of distortion.

4.

(*a*) Describe some form of radio navigational aid employing pulse transmitters emitting signals in a prescribed time relationship.

(*b*) Discuss the theoretical principles underlying the method of obtaining a position fix from such a system.

5.

(*a*) Draw a circuit diagram of an oscillator and reactance modulator suitable for use as the primary drive for an f.m. transmitter. Show how the centre frequency can be stabilised by reference to a crystal oscillator.

(*b*) A reactance valve of mutual conductance g_m is connected across a parallel-tuned circuit consisting of an inductance *L* and capacitance *C*.

A capacitance C_1 is connected between the anode and grid of the valve and a resistance *R* between grid and cathode. Calculate approximately the percentage shift in the resonant frequency of the tuned circuit after shunting it by the reactance valve.

6.

(*a*) What special difficulties are encountered in the design of high power v.l.f. transmitters to operate at specific frequencies in the range of 20 - 50 kc/s? Describe how modern materials and techniques may be used to solve these problems.

(*b*) Three separate aerials are equally spaced in a straight line. Explain with the aid of a circuit diagram how to excite them all in the same phase from a single remote transmitter.

7.

(*a*) Give an account of the relative merits of resonant and non-resonant aerials and arrays suitable for use with h.f. transmitters.

(*b*) A horizontal half-wave aerial is fixed at a height of three-quarters of a wavelength above a perfectly conducting earth. Show mathematically that there are three lobes in the vertical polar diagram of the system.

8.

Give a block diagram of an equipment suitable for measuring the effective height of the E, F_1 and F_2 layers of the ionosphere. Sketch the shape of a typical record, comment on any special features and account for the various discontinuities or anomalies in the curves.

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GRADUATESHIP EXAMINATION—PART IV

ELECTRONIC MEASUREMENTS

20th May, 1955 — 10 a.m.–1 p.m.

Candidates are required to answer FIVE questions only

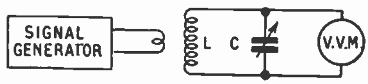
(1 weber/metre^2 = 10^4 gauss)

1\.
What is meant by an electrometer valve?

Give an example of its use in electronic measurement.

Describe the construction of an electrometer triode, showing how its design affects its properties.

2\.
(*a*) The following circuit is used to determine the r.f. resistance of the coil L at 10 Mc/s.



With C tuned to resonance, its value is 145 pF. When C is detuned so that the valve voltmeter reads ½ of its reading at resonance, the values of C are 142 pF and 148 pF.

Calculate the r.f. resistance of L, deriving any formulae used.

(*b*) The accuracies of calibration of the voltmeter, and of the frequency scale of the signal generator are ± 1% each. The calibration accuracy of the capacitor C is ± 0·2 pF and the stray capacitance does not exceed 4 pF. Calculate the accuracy to which the r.f. resistance may be determined.

3\.
Describe, with the relevant theory, a method of determining the primary constants of a transmission line.

4\.
(*a*) Discuss the possible sources of error in measurement of alternating currents with a multirange rectifier instrument.

(*b*) Such an instrument consists of a moving coil meter, bridge rectifier and current transformer. The moving coil consists of 300 turns of wire wound on a square former of side 1·5 cm. The flux density in the air gap is 1,450 gauss and the control spring exerts a torque of 0·5 gm-cm at full-scale deflection. Calculate the turns ratio of the current transformer if the meter is to give full-scale deflection for 1 A r.m.s.

5.

Describe the construction and operation of one type of scale-of-ten counting tube. Give details of the method of interconnection of two successive tubes in a scaling circuit.

6.

Detail a method of measurement of the flux density in the air gap of the permanent magnet of a loudspeaker. Show how this method may be modified to measure the variation in flux density over the length of the air gap. Illustrate your answer with values appropriate to a magnet with a flux density of approximately 10,000 gauss in the air gap of a speech coil diameter 2 cm.

7.

Describe how the frequency deviation may be monitored in a variable frequency f.m. signal generator

8.

How may the inductance of an iron cored inductor be measured at 50 c/s by a.c. bridge methods, when the inductor is carrying a superimposed direct current? What type of detector is most suitable? Give reasons for your choice.

If the inductor has 10 H inductance with 50 mA d.c., and 500 Ω resistance, calculate the approximate values of the bridge components.

9.

Describe in detail the measurements that must be made in order to construct the i.f. resonance curve for a domestic radio receiver. Discuss the significance of the 3 dB and 20 dB bandwidths, and the effect of using 1,000 c/s instead of 400 c/s as the modulating frequency of the signal generators.

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GRADUATESHIP EXAMINATION—PART IV

AUDIO FREQUENCY ENGINEERING

20th May, 1955 — 2.30–5.30 p.m.

Candidates are required to answer FIVE questions only

1.

A ribbon loudspeaker has the following constants:—

Ribbon length	5 cm
Width	0·6 cm
Thickness	0·0005 cm
Density	2·7 gm /c.c.
Specific Resistance	2·82 microhms/cm³
Flux Density	8×10^3 gauss
Horn Cut-off	1 kc/s

Assume a current of 1 A r.m.s. in the ribbon at a frequency of 5 kc/s.

Calculate the ribbon velocity, excess pressure at the mouth of the horn, and the electrical impedance of the ribbon.

2.

Two identical condenser microphones with the following characteristics are set up for free field reciprocity calibration:—

Capacitance	250 pF
Diaphragm area	2 cm²
Polarising Voltage	250 V
Load Resistance	100 MΩ

If the distance between diaphragm faces is 10 cm an alternating potential of 10 V with $\omega = 10^4$ radians/sec is applied to microphone X, and an e.m.f. of 30 V is developed across microphone Y, what is the sensitivity of each microphone?

3.

A three-stage resistance-coupled audio amplifier has a gain of 75 dB, the input impedance is 1 MΩ and the output load 1 MΩ. The three stages are identical and the triodes valves used have the following characteristics:—

Anode-grid capacitance	4·3 pF
Anode-cathode capacitance	2·0 pF
Grid-cathode capacitance	25 pF (*including wiring strays*)
$V_a = 250$ V	$g_m = 2{\cdot}3$ mA/V
$V_g = -4{\cdot}6$ V	$\mu = 32$
$I_a = 6{\cdot}0$ mA	$r_a = 14{,}000$ ohms

Determine the noise voltage appearing across the output load due to (*a*) Johnson noise and (*b*) Shot noise. (*No feedback will be used or assumed*).

4.

A series resonant equaliser is to have an impedance of 75 Ω at a resonant frequency of 1,000 c/s and an impedance of 600Ω at 875 c/s.

What are the values of L, C, and R?

5.

The recording characteristic of a lateral cut gramophone record has a velocity/frequency slope of +3 dB per octave.

The amplitude at 30 c/s is 0·001 cm.

(*a*) Over a frequency band of 30-10,000 c/s, what is the maximum velocity, and at what frequency will this occur?

(*b*) If the effective stylus mass is 3 milligrams, what is the minimum playing weight of the pick-up needed to maintain the stylus in contact with the groove walls? (*Assume an included angle of 90°, $g = 981$ cm/sec^2, and ignore pinch effect and lateral stiffness of movement.*)

6.

An audio amplifier requires the following d.c. power supplies:—

(*a*) 250 V at 20 mA with maximum ripple 100 μV with a source impedance of 10 ohms.

(*b*) 6·3 V at 1 A with a maximum ripple of 300 μV.

Design a power supply unit to meet the above requirements and give your reasons for the particular circuit used.

7.

Discuss the acoustic properties required in studios for recording (*a*) chamber music, (*b*) symphonic music, and (*c*) speech. How would you measure these properties, and what steps would you take to control them?

8.

A moving coil microphone has a diaphragm of effective area 5 cm^2, with a compliance of 3×10^{-8} cm/dyne. The coil has 50 turns of 1·5 cm diameter, with a d.c. resistance of 100 Ω. The total effective mass of the diaphragm coil is 0·25 gm, and the flux density is 5×10^3 gauss.

What is the open circuit voltage of the unit when operated in a sound field of 1 dyne/cm^2 at frequencies of:—

(*a*) 100 c/s (*b*) 400 c/s (*c*) 1,000 c/s

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GRADUATESHIP EXAMINATION—PART IV

TELEVISION

20th May, 1955 — 2.30 - 5.30 p.m.

Candidates are required to answer FIVE questions only

1.

Derive the formula for the bandwidth of a television signal. If the field repetition frequency is 50 per second, aspect ratio is 1·25, line blanking is 10% of the line period and frame blanking is 8% of the frame period and horizontal resolution is the same as vertical resolution, calculate the number of lines required in the picture if the bandwidth is approximately 6 Mc/s (*a*) using interlaced scanning and (*b*) sequential scanning.

2.

What is meant by the d.c. component in a television signal? How is it removed and restored? What are the effects of removing the d.c. component?

3.

A tuned circuit in the grid of an i.f. amplifier has a tuning capacitor of 39 pF zero temperature coefficient. The self-capacitance of the inductor is 3 pF and the wiring and valve capacity add a further 8 pF at 20°C.

The resonant frequency at 20°C is 30·00 Mc/s and at 40°C is found to be 29·85 Mc/s.

What should be the type of the 39 pF capacitor and its temperature coefficient if it were required to correct this frequency drift?

4.

In order to reduce the visibility of the line structure in a television picture, spot wobble is sometimes applied. Indicate how this is accomplished, and comment on the effect on picture definition according to the amplitude of oscillation.

If the line of sight is slowly moved up or down a normal television picture, a strobing effect occurs. Can this be affected by spot wobble?

5.

Describe briefly FIVE of the following television terms:—

(*b*) Intercarrier sound.
(*a*) I and Q channels.
(*c*) Astigmatism.
(*d*) Coma.
(*e*) Noise factor.
(*f*) Sound rejector.

6.

If Band I and Band III television transmitters are co-sited, and have the same effective radiated power, what factors may affect the relative magnitudes of the Band I and Band III signals at the receiver? Give typical figures where possible.

7.

Describe the action of a cascode amplifier and draw the circuit of such an amplifier, oscillator and frequency changer suitable for a television receiver. Show which connections will be affected on switching from one channel to another.

8.

Describe the construction of the scanning coils of a cathode ray tube in a television receiver.

Calculate the power developed in a scanning coil of inductance L, resistance R, when the current wave form is a saw-tooth of frequency f.

The British Institution of Radio Engineers

(Founded in 1925. Incorporated in 1932.)

GRADUATESHIP EXAMINATION—PART IV

VALVE MANUFACTURE AND TECHNOLOGY

20th May, 1955 — 2.30 - 5.30 p.m.

Candidates are required to answer FIVE questions only

1.

What is meant when an oxide coated emitter is defined as an Excess Semi-Conductor and outline an experiment which proves this definition to be valid.

2.

Derive the relationship between the mutual conductance, amplification factor and anode impedence of a triode valve. Express the way in which these parameters vary with electrode geometry.

3.

Outline the factors which dictate the choice of material used for the following components and describe methods by which these components can be manufactured in production quantities:

(*a*) Grids for receiving valves.

(*b*) Anodes for receiving valves.

(*c*) Modulating and accelerating electrodes for cathode ray tubes.

4.

Upon what consideration does the noise level of a valve used in the first stage of a high gain audio amplifier depend? Describe some of the design features which distinguish valves primarily intended for this application.

5.

Make a critical appraisal of the junction transistor as an alternative to the thermionic valve and preface your assessment with an outline of the physics of controlled impurity semi-conductors.

6.

Define the following effects, stating both the type of electron tube and the application in which these effects are most prominent. Outline steps which can be taken in the design and manufacture of such electron tubes to minimise these effects:

(*a*) Positive Ion Burn.

(*b*) Negative Ion Burn.

(*c*) Solarization.

(*d*) Screen Piling.

7.

State the various causes of the end of useful life in:

(*a*) An audio frequency output valve

and (*b*) a direct viewing television cathode ray tube.

What single feature in the manufacturing processes of these devices has the greatest bearing upon their life?

8.

Explain with the aid of diagrams the basic operation of a reflex klystron and two ways in which the working frequency of such tubes can be adjusted over a limited range.

ANSWERS TO NUMERICAL QUESTIONS

Part I — Physics

1. 25·6° C.

2. (*b*) 9 ft.

3. (*b*) 4 cm; 12 cm behind the mirror.

4. (*a*) 45 cm. (*b*) 660 m. (*c*) $2{\cdot}24 \times 10^6$ cals.

5. (*a*) 100 cm. (*b*) 19·125 cm. (*c*) 42·7%.

6. 9·26 dyne-cm.

7. (*a*) 33·3 V. (*b*) 0·004167 Joules.

9. (*b*) (i) $\frac{384}{2809}$W. (ii) $+\frac{488}{318}$V. (iii) $-\frac{496}{318}$V.

10. (*a*) $1{\cdot}5 \times 10^8$. 7·5 V. 15 V.

(*b*) 48 ohms.

(*c*) 25,000 dynes. 0 dynes.

Part II — Principles of Radio Engineering

1. (*a*) When $I_a = 2{\cdot}5$ mA. (*b*) 13·5 mW.

2. (*b*) Series resistance of 1 megohm.

(*c*) 6·25%.

3. (*a*) $i = 0{\cdot}04 \sin (2000\ \pi t - \frac{\pi}{4})$.

(*b*) 40 mW. (*c*) 1·6 μF.

4. (*c*) 247·5 c/s.

5. (*a*) 3·4 V.

7. (*a*) 0·878 mA. (*b*) 18·4 mA.

8. (*a*) 320 ohms. (*b*) 0. (*c*) 156 mA.

Part IIIa — Mathematics

1. (*a*) $k = 0{\cdot}0131$, $n = 1{\cdot}286$.

(*b*) $-1000 \pm 2000j$.

2. (*a*) $-15120x^4y^3$, $\frac{448}{9y^5}$

(*b*) (i) £147 18s. (ii) £148 12s.

3. (*a*) $x = 14{\cdot}33$.

(*b*) $x = 2n\pi + 27° 18'$ *or* $2n\pi + 78° 58'$.

4. (*a*) $LG = RC$

(*b*) $300 \angle -6° 21'$

5. (*b*) $-\frac{3x - 1}{4y + 3}$

(*c*) (i) 2 cosec x.

(ii) $e^{ax} (b \sinh bx + a \cosh bx)$.

6. (i) $\frac{1}{2}$ (ii) $\frac{2}{3}$ (iii) 1. $\frac{2}{19}$

7. (i) $-\frac{3}{2} \cos (2x+3) - \frac{2}{5} \sin (4-5x) + const.$

(ii) $\frac{1}{4}e^{4x} - x^3 + const.$

(iii) $2 \log (1 + x^3) + const.$

(iv) $3 \log (\log x) + const.$

$-2\frac{1}{8}$.

8. $3\frac{1}{3}$.

9. $m = -2b$, $n = p^2 + b^2$.

Part IIIb — Advanced Radio Engineering

1. $L_k = 0{\cdot}24$ H. $C_k = 0{\cdot}667\mu$F.

2. $\theta_{max} = \pm\ 48°36'$ and $\pm\ 131°24'$.
   $\theta_{min} = \pm\ 30°, \pm\ 90°, \pm\ 150°$.

4. gain approx. 0·96.
   input capacitance = 4·14 pF.
   input admittance = $52{\cdot}2 \times 10^{-6}$ mhos.

5. $E_g = 371$ volts.

7. f approx. 7 c/s.

Part IV — Radio Reception

1. (*a*) 3·07 mH.
   (*b*) 260 µV/m.

2. −0·1 dB.

4. (*b*) 3 V.

5. R = 267 k Ω
   C = 89·5 pF.

6. 1·42 V.

8. 179 turns, 33 laminations.

Part IV — Radio Transmission

1. (*b*) $Z_i = \dfrac{r_a + R}{\mu + 1} = \dfrac{r_a + R}{1 + g_m r_a}$

2. (*b*) voltage gain $= g_m \dfrac{L}{C\,r}$.
   band width $= \dfrac{\sqrt{3}\,R}{2\,\pi\,L}$.

5. (*b*) $100 \left\{ 1 - \sqrt{\dfrac{C}{C + g_m\,RC_1}} \right\}$.

Part IV — Electronic Measurements

2. (*a*) 1·314 ohms.
   (*b*) Maximum error 15·7%, including 5·7% due to stray capacitance.

4. (*b*) 180 : 1.

Part IV — Television

1. (*a*) 621. (*b*) 439.

3. −0·000640 pF/°C.

8. $LI^2 f + \frac{1}{3} RI^2$.

   Where I is the current to deflect from the centre to one side of the picture.

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The British Institution of Radio Engineers

FOUNDED 1925. INCORPORATED 1932.

"To promote the general advancement of and to facilitate the exchange of information and ideas on radio science and engineering."

GRADUATESHIP EXAMINATION PAPERS

NOVEMBER 16th, 17th and 18th 1955

9, BEDFORD SQUARE,
LONDON, W.C.1

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Price—Two Shillings and Sixpence—Post Free

The British Institution of Radio Engineers

(Founded in 1925. Incorporated in 1932.)

EXAMINATION REGULATIONS

(with effect from November 1956)

Conditions of Entry

Entries may only be accepted from:

(*a*) Students or Associates of the Institution whose subscription for the current year has been paid.

(*b*) Candidates who have lodged with the General Secretary in London a duly completed proposal form (P) for election as Graduate, Associate Member or Member, and whose eligibility has been approved.

Scheme of the Examination

With effect from November, 1956, the Graduateship Examination of the Institution will consist of two separate sections sub-divided into parts as follows:—

SECTION A

(1) Physics—two three-hour papers.

(2) Principles of Radio and Electronics—one three-hour paper.

(3) Mathematics—one three-hour paper.

SECTION B

(3) Mathematics—one three-hour paper (if not taken in Section A).

(4) Advanced Radio and Electronic Engineering—one three-hour paper.

(5) Specialist subject—one three-hour paper—to be chosen from:—

Audio Frequency Engineering
Applied Electronics
Electronic Measurements
Radar Engineering and Microwave Techniques
Radio Reception
Television
Valve Technology and Manufacture

Candidates are required to complete Section A before proceeding to Section B but may choose in which section Mathematics will be attempted. Candidates may enter for only one section of the examination on any one occasion.

A candidate who has qualified for exemption from the Physics papers and any other subject in Section A may take the remaining subject at the same time as Section B.

Syllabus

The syllabus of the examination is set out in the 23rd edition of the Membership and Examination Regulations.

Successes under Earlier Regulations

Any candidate who has satisfied parts of the examination prior to November, 1956, will be credited with this success on a subject-for-subject basis, and will not be required to sit these parts of the new examination.

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GRADUATESHIP EXAMINATION—PART I

PHYSICS

16th November, 1955 — 2.30–5.30 p.m.

Candidates are required to answer SIX questions only of which not more than THREE may be taken from one section.

Sections A and B MUST *be answered in separate books.*

SECTION A (Heat, Light and Sound)

1.

Describe an experiment to verify Charles' Law for a gas.

100 cc of dry gas is contained in two equal containers joined by a tube of negligible volume. Both containers are initially at 25° C. One container is then heated to 100° C. The final pressure is 80 cm of mercury. What was the initial pressure in the containers? (*Neglect expansion of containers.*)

2.

Explain the underlying theory and briefly outline the experimental procedure of a method for determining the refractive index of either a liquid or a solid by a critical angle method.

A metal tank is filled with a liquid of refractive index 1·6; a thin circular opaque disc floats centrally over a luminous point source which is 7 cm below the liquid surface. What is the least radius of this disc that the light source shall not be visible from outside the tank?

3.

Explain how you would determine the velocity of sound in air by a resonating air column method.

Derive an expression for the apparent frequency of the note heard by an observer who is moving with velocity v towards a stationary sound source of frequency n.

4.

(*a*) A calorimeter contains 30 gm of water and 8 gm of ice all at 0° C. Steam at 100° C is passed into the water until all the ice has just melted, the temperature remaining at 0° C. What is the weight of water now in the calorimeter? (Latent heat of steam=540 calories per gm and latent heat of fusion of ice=80 calories per gm.)

(*b*) A sonometer wire of vibrating length 50 cm is stretched by a weight of 5 kilograms. When sounding at its fundamental frequency it emits a note of 500 c/s. What is the mass of this length of sonometer wire? ($g = 980$ gm/cm^2.)

(*c*) The focal length of a thin double convex lens is 20 cm, the radius of one surface is 15 cm and the other 20 cm. What is the refractive index of the material of which it is made?

5.

(*a*) Determine the velocity with which a lead bullet—initially at 25° C—strikes a target if the heat generated is all absorbed and just melts the bullet. (Melting point of lead=325° C; specific heat of lead = 0·03 cal/gm/°C; latent heat of fusion of lead = 5 cal/gm; J = $4{\cdot}2\times 10^7$ ergs/cal.)

(*b*) Explain the terms :—pitch, beats, end correction, adiabatic change, timbre.

(*c*) The shortest distance at which a person suffering from long sight can focus is 90 cm. What is the focal length and type of lens which will enable him to just focus at a distance of 45 cm from his eyes?

SECTION B (Magnetism and Electricity)

6.

What is meant by the term electric potential? Show that the potential due to a point charge q at a distance r is given by $\frac{q}{r}$.

A soap bubble of radius 5 cm has a charge of 80 e.s.u. What is its change in potential if the radius is decreased to 4 cm?

7.

Describe an experiment to determine the strength of a magnetic field by means of a vibration magnetometer.

A short bar magnet lies along a magnetic field of 0·18 gauss. If there is a neutral point 6 cm from the centre of the magnet, calculate its magnetic moment.

8.

(*a*) Establish the relation between the resistors in each arm of a Wheatstone bridge in the balanced position.

(*b*) A meter movement having a resistance of 1 Ω gives a full scale deflection with a current of 1 mA. Explain how you could use this movement to measure (i) voltages up to 100 V. (ii) currents up to 10 A.

9.

(*a*) Calculate the time taken for an electric kettle to raise 1 litre of water from 10° C to 100° C if the heating element has a constant resistance of 80 Ω and the mains supply is 250 V. (J = 4·2 Joules/calorie.)

(*b*) State Faraday's Laws of electrolysis.

When a current of 2 A flows through a copper voltameter for 5 minutes, the cathode weight increases by 0·18 gm. Calculate the E.C.E. of the copper.

10.

(*a*) The coil of a moving coil galvanometer has 400 turns of mean area of 5 cm². A deflection of 1° is produced by a current of 1 μA against a restoring couple of 1·0 dyne-cm. What is the strength of the field in which the coil is suspended?

(*b*) A circular coil of 100 turns and mean radius 10 cm rotates about a diameter as axis, and at right angles to a magnetic field of 5 gauss. What is the maximum value of the e.m.f. induced round the coil if it rotates 10 times per second?

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GRADUATESHIP EXAMINATION—PART II

PRINCIPLES OF RADIO ENGINEERING

17th November, 1955 — 10 a.m.–1 p.m.

Candidates are required to answer SIX questions only

1\.

Derive a simple equivalent circuit for a transformer, stating any assumptions made.

A triode valve with a g_m of 5 mA/volt and an R_a of 2000Ω supplies a loudspeaker through a 10 : 1 step down transformer in the anode circuit. Assume the transformer to be ideal and the loudspeaker to be a resistive load of 16Ω; what value of sinusoidal voltage is required at the grid in order to obtain 1 watt of output in the loudspeaker.

2\.

Explain the action of a diode detector used for the demodulation of an amplitude modulated wave.

What factors determine the detector efficiency? Show how distortion can occur with this type of detector.

3\.

A voltage of $V = 100 \sin \omega t + 20 \sin 2\omega t + 10 \sin 3\omega t$ is applied to a series circuit of L, C and R. Find the value of L which gives resonance at the second harmonic when $C = 1\,\mu$F, $R = 10\,\Omega$ and $\omega = 104$.

What are the r.m.s. values of current and voltage with this value of L?

4\.

Describe and explain the principle of a direct reading d.c. potentiometer. Show how it can be used to measure resistance, current and voltage.

5\.

A triode valve has the following characteristics:

V_g(V)	+1	0	−1	−2	−3	−4	−5
I_a(mA)	6·3	5	3·5	2	0·75	0·25	0

when $V_a = 150$ volts.

Given that the a.c. resistance is 10 kΩ, obtain the mutual conductance and the amplification factor. Derive the mutual characteristics for anode voltages of 180 V, 120 V and 90 V and find the effective mutual conductance for an anode load of 50 kΩ with a supply voltage of 200 volts.

6.

Sketch the simple circuit of a cathode ray tube employing electrostatic deflection and explain the function of the controls.

A cathode ray tube has an accelerating voltage of 2 kV and has a distance of 30 cm between the screen and the nearer edge of the deflecting plates. If the deflecting plates are 4 cm long and 2 cm apart, calculate the deflection sensitivity of the tube.

Derive any formula used.

7.

Describe a method for measuring the resistance of a tuned circuit. State what precautions are necessary for accurate measurement and discuss the relative advantages of the methods normally used.

8.

Define the terms Class A, B and C working, stating the relative advantages of each method for amplification.

A valve operating as a Class C amplifier is to be anode modulated by a Class B amplifier. If the total power output is 250 W with a modulation depth of 90%, find the necessary ratings of the power amplifier and modulator valves if they operate at efficiencies of 75 and 55% respectively.

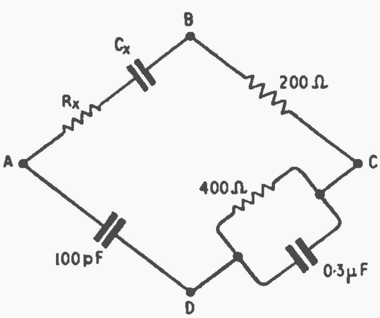
9.

Show the construction of a metal rectifier and explain its action. Draw the circuit of a full wave voltage doubling rectifier and state what factors determine the choice of the rectifier.

Discuss the choice of either inductance or capacitance input filters in specific circuits.

10.

What is meant by the loss angle of a capacitor.



In the above bridge, balance is obtained between the points B and D when a 50 c/s supply is connected across A and C.

Calculate the loss angle of the test capacitor represented by C_x with a series resistor R_x.

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GRADUATESHIP EXAMINATION—PART IIIa

MATHEMATICS

17th November, 1955 — 2.30–5.30 p.m.

Candidates are required to answer SIX questions only

1.

(*a*) The roots of a quadratic equation are $\alpha = 6 + 5i$ and $\beta = 6 - 5i$ respectively. Determine the equation.

(*b*) Draw graphs of the equations :—

$$3x + 2y = 7$$
$$5x - 2y - 17 = 0$$

Hence solve the equations for x and y.

2.

(*a*) In a certain circuit the frequency is $f = \dfrac{1}{2\pi\sqrt{(LC)}}$

If C is increased by a small quantity k, determine the approximate decrease in frequency in terms of f, k and C.

(*b*) If x is less than unity, determine the sum to infinity of the series

$$1 + 3x + 5x^2 + 7x^3 + 9x^4 + \ldots$$

3.

(*a*) If $P = \dfrac{V^2 \cos\theta}{Z}$, and the gain of power P_2 referred to P_1 is D decibels, where $D = 10 \log (P_2/P_1)$, deduce an expression for D in terms of the respective values of V, θ and Z, and calculate the gain of an amplifier in which :—

$V_1 = 0{\cdot}2$	$V_2 = 10$
$Z_1 = 10^5$	$Z_2 = 500$
$\cos\theta_1 = 1{\cdot}0$	$\cos\theta_2 = 0{\cdot}5$

(*b*) Obtain an expression for $\sin^4 x$ in terms of $\cos 2x$ and $\cos 4x$.

4.

(*a*) Express in polar form the quantity $\dfrac{a - jb}{a + jb}$.

(*b*) Express in the form $a + jb$ and represent on an Argand diagram each of the following :—

(i) $\dfrac{(3 + 2j)(1 - 4j)}{2 + j}$

(ii) $(4\angle 75^\circ)(2{\cdot}5\ \overline{\diagdown 15^\circ})$

(iii) $e^{3 + \frac{1}{3} j\pi}$

5.

(*a*) From first principles determine the derivative with respect to x of $\sin x$.

(*b*) Find the value of $\frac{dy}{dx}$ if $2x^2 - 3y^2 - 3x + 5y = 7$

(*c*) Differentiate with respect to x :—

(i) $\sin \log x$

(ii) $\frac{e^x}{1 + x^2}$

(iii) $\frac{1}{3} \cos^3 x - \cos x$

6.

Determine the value of V for which the expression $V \sin x + \frac{1}{3}\sin 3x$ is a maximum when $x = 60°$ as x varies. Find all the values of x between zero and 180° which make the expression a maximum or minimum for this value of V, and state which give a maximum and which a minimum.

7.

State Taylor's and Maclaurin's Theorems.

Use these theorems to expand the following expressions in powers of x :—

(i) $\log (x + h)$

(ii) $e^{\sin x}$

and state for what values of x the expansions are valid.

8.

Integrate with respect to x the following expressions :—

(i) $3 (x^2 + 1)^2$

(ii) $\sin 3x.\cos x.\, dx$

(iii) $e^{(3x-5)}$

(iv) $\sinh^2 x$

Evaluate also the integral : $\int_{\pi/6}^{\pi/3} \tan x.\, dx$

9.

Show that the equation : $x^2 \frac{d^2y}{dx^2} + \frac{dy}{dx} x + y = 0$

is satisfied by the relation : $y = a^2 \sin \log x$.

If $\frac{dy}{dx} = 4$ when $x = 1$, determine the value of a.

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GRADUATESHIP EXAMINATION—PART IIIb

ADVANCED RADIO ENGINEERING

18th November, 1955 — 10 a.m.–1 p.m.

Candidates are required to answer FIVE questions only

1.

Describe briefly the effects of negative feed-back on the performance of an amplifier.

Explain " negative voltage feed-back ", and by means of a circuit diagram, show how it can be achieved in a single stage, resistance coupled voltage amplier.

A single stage amplifier employs a valve having an amplification factor of 24, and an anode slope resistance of 8,000 Ω. The anode load resistance is 20,000 Ω and the cathode bias resistor is 1,000 Ω. Derive an expression for the output impedance with feedback, and calculate :—

(i) How much of the cathode resistor must be by-passed to a.c. to increase the output impedance to 25,000 Ω.

(ii) The stage gain under these conditions.

2.

Describe, with the aid of a circuit diagram, one method by which continuous sinusoidal oscillations can be maintained in a circuit containing resistance, capacitance and valves, but no inductance. Discuss the relative merits of this type of oscillator in relation to other types using inductors and capacitors.

Deduce an expression for the frequency of oscillation in terms of the constants of the feed-back network.

3.

Explain briefly the superheterodyne principle of reception, and state the factors which influence the choice of intermediate frequency.

With the aid of a circuit diagram, describe the action of a triode-hexode frequency changer for a superheterodyne receiver.

If such a receiver is required to cover a wave band of 200–500 metres, and the intermediate frequency is to be 450 kc/s, calculate :—

(i) The maximum and minimum frequencies of the beating oscillator.

(ii) The maximum capacitance of the oscillator tuning capacitor, assuming that the minimum value is 100 pF.

4.

With the aid of a circuit diagram, explain the action of a reactance valve in the production of a frequency modulated wave.

A pentode reactance valve of 2·5 mA/V has a capacitor of 25 pF connected between the anode and control grid, and a resistance of 800 Ω between control grid and cathode. Derive an expression for the admittance between the anode and cathode, and hence deduce the value of the shunt capacitance presented by this valve when connected across the tuned circuit of an oscillator operating at 1 Mc/s.

5.

Discuss briefly the relative merits of choke input and capacitor input filter circuits as used with full wave rectifiers.

A full wave rectifier with a reservoir capacitor of 8 μF is required to give 100 mA at 400 V. Estimate :—

(i) The secondary voltage of the transformer.

(ii) The peak current through the diode.

(iii) The degrees per half cycle over which the capacitor is discharging.

(iv) The depth of the ripple voltage.

Deduce any formula used, and state clearly any assumptions made.

6.

Explain with reference to a four-terminal network what is meant by :—

(i) Characteristic impedance.

(ii) Image impedance.

(iii) Propagation constant.

Design from first principles either a π or bridged-T type attenuator pad having an attenuation of 20 db when working between two 600 Ω impedances.

7.

Describe in detail, giving the relevant theory, one method of measuring each of the following quantities :—

(i) The self inductance of an r.f. coil, using a resonance method.

(ii) The mutual conductance of a triode valve under dynamic conditions, using a bridge circuit.

In each case give an account of the precautions necessary to ensure accuracy.

8.

Sketch the vertical polar diagram in a plane perpendicular to its axis of a horizontal dipole placed 1·2 wavelengths above a perfectly conducting earth.

Calculate the position of the maxima and minima of the lobe pattern, deriving the formula used.

9.

If the mutual inductance between the two windings of a transformer is M, derive the following :—

(i) An expression for the resistance and reactance reflected into the primary, when the total secondary resistance, reactance and impedance are respectively R_2, X_2 and Z_2.

(ii) An expression which shows how the relationship between the transformation ratio and the turns ratio of an audio frequency transformer varies with frequency when the secondary is on open circuit.

(iii) An equation for the critical coupling coefficient between two magnetically coupled r.f. coils which are tuned to the same frequency.

In (ii) and (iii), state any assumptions made.

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GRADUATESHIP EXAMINATION—PART IV

RADIO RECEPTION

18th November, 1955 — 2.30–5.30 p.m.

Candidates are required to answer FIVE questions only

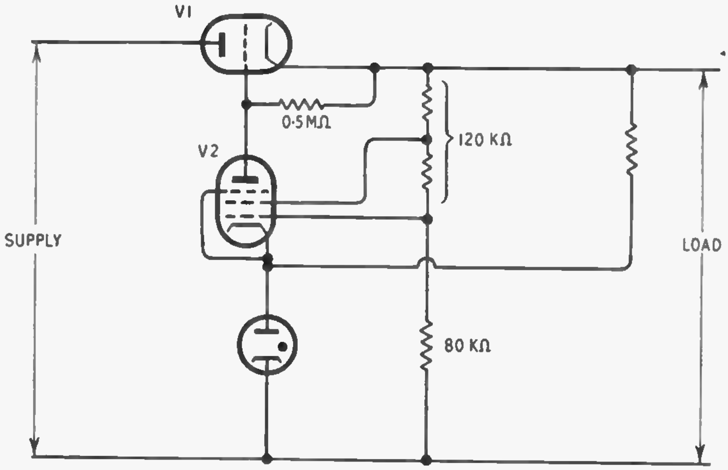
1.

What are the essential differences in requirements for discriminators for use in a.f.c. circuits and for demodulation of f.m. signals? How are these requirements met in the circuit design?

An a.f.c. circuit controlling the local oscillator of a receiver consists of a discriminator and a variable reactor. The variable reactor will change the frequency of the oscillator by 5 kc/s per applied volt. What must be the sensitivity of the discriminator, in volts/kc/s, if the i.f. drift is to be reduced to 5% of that without correction?

2.

Comment on the applications of the circuit given below as a voltage stabiliser :



In the above circuit, the valve constants are :—

V_1 : $g_m = 5{\cdot}25$ mA/V, $r_a = 800\ \Omega$. V_2 : $g_m = 1{\cdot}25$ mA/V.

Calculate the output voltage variation as a percentage of the input variation. Neglect the effect of screen voltage variation in V_2. State any other assumptions made, and derive any formulae used.

3.

A valve used as an a.f. amplifier has $r_a = 50$ kΩ and $\mu = 75$. The anode load is 250 kΩ and is coupled by a capacitor to a 1 MΩ resistor between grid and cathode of the next stage. Bias is provided by a resistor of 3000 Ω in parallel with a capacitor of 5 μF.

Calculate the frequency at which the stage gain is 3 db below the gain at mid-frequency. Derive any formulae used, and neglect the effect of the coupling capacitor.

4.

Discuss the design of an aerial coupling transformer for use in the medium wave band with an aerial of 200 pF capacitance.

What are the effects of using, with such a transformer, an aerial of considerably less capacitance and how may these effects be minimised?

An aerial coupling transformer has the aerial coil inductance of 1 mH and the tuning coil inductance 175 μH. The aerial may be represented by a capacitance of 200 pF. What must be the coupling factor in order that there should be not more than 2·5% mistuning of the tuned circuit at 1 Mc/s?

5.

Explain how tracking error between oscillator and r.f. circuits of a superheterodyne receiver affects the image rejection.

A receiver has an i.f. of 465 kc/s, and the local oscillator frequency is higher than the r.f. A single r.f. circuit of Q = 75 precedes the mixer stage. If the receiver is tuned to a frequency of 5 Mc/s, what is the image rejection, in db? By how many db is this changed if the r.f. circuit is tuned 2% high. State any assumptions made.

6.

Explain the operation of a cascode (grounded cathode—grounded grid) type of amplifier. What are the advantages of this type of circuit over a pentode amplifier in the v.h.f. band?

A cascode circuit consists of two triodes, having identical parameters μ, g_m and r_a. The load of the circuit is a pure resistance R.

Show that, when inter-electrode capacitances are neglected, the circuit is equivalent to a single valve with parameters:—

$$\mu' = \frac{\mu(\mu+1)R}{r_a + R}; \qquad g'_m = g_m \text{ and with anode load } R.$$

7.

Discuss the factors controlling the coupling factor required in the i.f. transformer feeding the detector stage of a receiver.

A pentode i.f. amplifier has a tuned transformer for anode load. The Q-factor of the coils is 75 at the i.f. of 450 kc/s. The transformer secondary feeds the detector diode of a double diode, which has a load of 0·5 MΩ. The pentode anode is coupled directly to the a.g.c. diode anode, which is loaded by 1 MΩ. The pentode has r_a = 800 kΩ, and both primary and secondary are of 1·25 mH inductance.

Calculate the coupling factor to give critical coupling under these conditions. State any assumptions made.

8.

Describe the construction and action of a Marconi-Franklin series phase aerial (end fire array).

Derive an expression for the polar diagram in the horizontal plane, of such an aerial containing four vertical loops. Sketch this polar diagram.

9.

What is meant by the conversion conductance of a frequency changer?

How does the conversion conductance of a triode-hexode vary with operating conditions, and what steps are taken to minimise the variation over the tuning range of a receiver?

The British Institution of Radio Engineers

(Founded in 1925. Incorporated in 1932.)

GRADUATESHIP EXAMINATION—PART IV

RADIO TRANSMISSION

18th November, 1955 — 2.30–5.30 p.m.

Candidates are required to answer FIVE questions only

1.

Describe the effects and uses of negative feedback in the audio frequency stages of a transmitter.

A r.f. transmitter which provides 50 kW unmodulated carrier is modulated to a depth of 100% by sinusoidal tone; the a.f. feed-back is now increased by 4 db; calculate the resultant percentage modulation and average r.f. power output.

2.

Discuss the characteristics of v.h.f. propagation, and show by calculation the effects of distance, wavelength, transmitting and receiving aerial height on the strength of the received signal. Assume for the calculation that the earth is perfectly reflecting and flat.

3.

Draw the circuit diagram of a high tension unit with series stabiliser suitable for supplying the low power stages of a television transmitter. Describe fully how the stabiliser reduces variations of load voltage when the load current varies and when the input mains voltage varies.

If the effective internal resistance of the power unit supplying a series stabiliser is 500Ω, and the d.c. amplifier driving the series stabiliser valve has a gain of 100, calculate the resultant output impedance of the stabilised supply at very low frequencies. The series valve has the following characteristics:—

$$g_m = 10\text{ mA/V.}; \quad r_a = 1500\Omega.$$

4.

Explain the meaning and significance of aerial gain. What factors affect aerial gain?

A transmitter is amplitude modulated with sinusoidal tone to a depth of 30%. What change in modulation depth will be necessary to maintain constant audio frequency output from a distant receiver working without a.g.c. if the gain of the transmitting aerial is changed from 9 to 6 db, and at the same time the transmitter power is reduced from 50 to 40 kW?

5.

Draw a schematic diagram and describe the action of a modulation monitor which gives a continuous and reasonably accurate indication of the depth of modulation of a r.f. carrier.

6.

A transmitter is supplied with power from a 400 V three phase mains supply, and the power input connections are switched from star to delta to obtain low and high power output conditions. If each branch of the three phase load presents an impedance of 23 Ω, and the ratio of resistance to reactance is 3 to 2, what will be the line current, the input power, and the power factor when the branches are:—

(*a*) Star connected (*b*) Delta connected

Assume that the impedance of the mains is negligible.

7.

Draw the circuit diagram of a high power Class C amplifier using two triodes in push-pull. Include h.t., bias and filament supply connections, and tank circuit and neutralising arrangements.

If the effective anode to anode load resistance presented by the tank circuit is 2000 Ω, and the total anode to anode tank capacitance is 100 pF, including stray capacitances, calculate approximately the following:—

(*a*) The circulating current.

(*b*) The anode to anode voltage.

(*c*) The effective Q of the tank circuit.

when the stage is delivering 100 kW output at 20 Mc/s.

8.

With the aid of circuit diagrams, explain the theory of simple L type transforming networks (upwards and downwards transducers) and calculate the values of capacitance and inductance which could be used to transform an impedance of $50+j20\,\Omega$ into a pure resistance of 300 Ω at a frequency of 1 Mc/s.

9.

Discuss the advantages and disadvantages of concentric tube r.f. transmission lines.

Calculate the parallel conductance and susceptance presented by a loss free concentric transmission line terminated by a parallel conductance of 25 millimhos and a parallel susceptance of $-j12{\cdot}5$ millimhos. The transmission line has a characteristic impedance of 75 Ω and is $\frac{3}{4}\,\lambda$ long.

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GRADUATESHIP EXAMINATION—PART IV

ELECTRONIC MEASUREMENTS

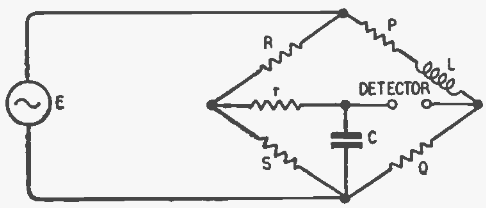
18th November, 1955 — 10 a.m.–1 p.m.

Candidates are required to answer FIVE questions only

1.

Describe with the aid of suitable diagrams, the measurements which would be necessary to determine whether a given sample of iron would be suitable for use as core material for the power supply transformer in a radio receiver. Explain how eddy current loss may be separated from hysteresis loss.

2.



The circuit shown above is that of the Anderson Bridge for the measurement of inductance. Prove that when the bridge is balanced:—

$$PS = QR$$

$$\text{and} \quad L = CQ\left\{r\left(1 + \frac{R}{S}\right) + R\right\}$$

Such a bridge is constructed using the following components :—

One	1μF capacitor	One	5 to 5000 Ω variable resistor
One	1 to 50 Ω variable resistor	Two	1000 Ω fixed resistors

Determine the maximum and minimum values of inductance which can be measured by suitably arranging these components in the bridge.

3.

Describe the following methods of measuring non-linear distortion in an audio amplifier:—

(*a*) Harmonic Analysis.

(*b*) SMPTE (Society of Motion Picture and Television Engineers).

(*c*) C.C.I.F. (International Telephone Consultative Committee).

Illustrate how these tests would be applied in practice, and compare the results of such tests with the distortion which can be detected naturally.

4.

During the testing of a 600Ω v.h.f. telephony repeater, only one signal generator having an output impedance of 75Ω is obtainable. Design an L-type pad to give correct matching, and calculate its attenuation and insertion loss, in db. If the input and output connections of the pad are accidentally reversed, what will then be the attenuation and insertion loss? What measurements would you make:—

(*a*) To check for correct matching.
(*b*) To determine the attenuation.
(*c*) To determine the insertion loss.

Which of the above measurements should be applied to find out whether the pad has been properly connected?

5.

The following specification is that of a typical stabilised power supply :

A.C. Input. 200-250 volts ; 40-60 c/s.

D.C. +ve Output. 20-500 volts at 0-300 mA.
Stability : 400 : 1 for 10% mains voltage change.
Source Impedance : 3 ohms.
Hum level : less than 8 mV on full load.

D.C. −ve Output. fixed, − 170 V ; variable, 0 to − 170 V.
Current : 0·5 mA max.

A.C. Outputs. Two Outputs of 6·3 V at 5 A.

Describe in detail the experiments which you would perform in order to check this specification and state the accuracy you would consider sufficient for each measurement.

6.

Draw the circuit diagram and explain the operation of a Miller Integrator sawtooth generator. Describe how the linearity of the output waveform may be checked.

7.

Describe the construction and explain the method of operation of a slotted line, suitable for use in the frequency range 100—200 mc/s. Show how an unknown impedance may be measured using this instrument.

8.

A series of measurements on a toroidal coil were performed by means of a " Q " meter giving the results tabulated below.

Q	75	110	157	212	215	209	192
f (kc/s)	300	250	200	150	100	75	50
C (pF)	45·4	75·4	135·4	259·6	615	1112	2535

Calculate the self-capacity of the coil, deriving any formula used and check the result graphically. By means of graphs, or otherwise, calculate the inductance.

After analysing the above results, in what range of frequency would you carry out additional measurements to obtain a more accurate value for the self-capacity ?

9.

An instrument is required to check the frequency of a 100 kc/s crystal oscillator, the minimum accuracy required being one part in 10^4. Describe in detail one instrument which could perform this measurement. Include in your answer a circuit diagram and state how you would cross check your measurements.

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GRADUATESHIP EXAMINATION—PART IV

TELEVISION

18th November, 1955 — 2.30–5.30 p.m.

Candidates are required to answer FIVE questions only

1.

A television receiver is facing magnetic north. The edges of the picture are made to coincide exactly with a mask. The receiver is turned upside down, but still facing magnetic north. Approximately how far will the edges of the picture now be from the mask.

Vertical component of Earth's magnetic field $= 0{\cdot}4$ gauss.

C.R.T. anode voltage $= 10$ kV.

Anode to screen distance $= 30$ cm.

$e/m = 1{\cdot}8 \times 10^8$ coulombs/gm.

$= 1{\cdot}8 \times 10^7$ e.m.u./gm.

Derive any formulae used.

2.

Explain the action of a surge-limiting component in a series connected heater chain of a television receiver, and describe the qualities which govern the choice of a suitable type.

A receiver has series heater connections and metal-rectifier h.t. supply. Describe the difficulties in ensuring adequate protection by the mains fuse, including the condition of d.c. supply.

3.

A sawtooth waveform is applied to the grid of a valve. The voltage increases slowly from beyond cut-off to zero bias, and is then switched rapidly to beyond cut-off. The anode load is a coil of inductance 500 mH, and the anode current at zero bias is 100 mA.

Sketch the waveforms of anode voltage, anode current, and grid voltage, and calculate the capacity of the anode coil if the peak anode voltage is 10 kV.

4.

Describe:—

(*a*) A circuit which will insert frame synchronising broad pulses into a waveform of line synchronising pulses, assuming that suitable gating pulses are available.

(*b*) A circuit which will extract a frame synchronising pulse from the complete synchronising waveform.

5.

Explain, in detail, the difference between positive and negative modulation of television signals.

Synchronising pulses occupy 10% and blanking pulses a further 6% of the total time for a waveform. Calculate the average power transmitted by a black signal and a peak white signal for both types of modulation, as a proportion of peak power. Assume that the carrier can be modulated to zero level, and that blanking level is black level, with 70:30 picture synch. ratio.

6.

Three differing types of magnetic focusing devices may be commonly used: employing electro-magnets, ring magnets and opposing ring magnets of high coercive force. Sketch the cross section of each of these units, and indicate the shapes of the fields produced by drawing particular lines of force.

Draw a typical graph of field strength at points on the axis of each unit, and briefly indicate how measurements of such fields could be made.

7.

(*a*) Describe networks suitable for connecting aerials to television receivers if:—

(i) The receiver has a single input terminal and two aerials tuned to widely differing frequencies.

(ii) The receiver has two input terminals (Band I and Band III) but a single wide-band aerial.

(*b*) Show how, in a British system receiver, sound and vision i.f. signals may be separated for amplification, and how the unwanted signal may be rejected in each i.f. amplifier.

8.

Discuss briefly FIVE of the following:—

(*a*) Adjacent channel rejection.

(*b*) Timebase linearity.

(*c*) Mosaic.

(*d*) Overshoot.

(*e*) Positive and negative ghosts.

(*f*) Transient response.

(*g*) Synchronous detection.

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GRADUATESHIP EXAMINATION—PART IV

AUDIO FREQUENCY ENGINEERING

18th November, 1955 — 2.30–5.30 p.m.

Candidates are required to answer FIVE questions only

1.

Comment on the effects of amplitude distortion in audio frequency systems, and give examples of how this type of distortion can arise.

A moving coil microphone generates a voltage, having a non-sinusoidal waveform, as a result of a fluctuating pressure wave impinging on its diaphragm. If the coil, of inductance L Henries and resistance r ohms, is connected to a load resistance of R ohms, derive an expression for the instantaneous current in the circuit.

2.

Define the terms, characteristic impedance, attenuation constant, and phase constant.

Design a low-pass, m-derived, π section filter having a characteristic impedance of 500 ohms, a cut-off frequency of 10 kc/s and infinite attenuation at a frequency of 10·5 kc/s. Derive from first principles the formulae used.

3.

Discuss in detail the characteristics of speech and hence describe the essential requirements of a sound reinforcing system for a large lecture theatre.

4.

State the effects on the performance of an audio frequency amplifier of applying negative voltage-feedback and justify your statements by reasoning from first principles.

5.

Define the units known as the decibel and the phon, and explain their respective uses.

A non-reactive T-network having series elements of value 125 ohms each and a shunt element of value $66\frac{2}{3}$ ohms is connected between a source and a receiver each of which has an internal impedance of 75 ohms resistive. Calculate the insertion loss, in decibels, due to the T-network.

6.

Write a short account of an experiment to determine the reverberation time of an auditorium, giving details of the apparatus required.

A room of dimensions 80 ft $\times$ 45 ft $\times$ 18 ft has a reverberation time of 4 sec. Calculate the average coefficient of absorption.

7.

Explain the forms of distortion which can occur in the stylus-groove combination of a laterally modulated disk recording play-back system.

Derive an expression for the amplitude distortion produced when the axis of movement of the pick-up needle is at an angle α to a radius of the record.

8.

The frequency response of a certain moving coil microphone was improved by means of an acoustic resonator coupled to the rear side of the diaphragm.

The resonator consisted of a cavity, having rigid walls and an effective volume of 1·2 cu in, and a tube of length 1 in and of diameter 0·5 in coupling the cavity to the diaphragm.

Calculate the resonant frequency of this acoustic system deriving any formulae used.

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GRADUATESHIP EXAMINATION—PART IV

VALVE MANUFACTURE AND TECHNOLOGY

18th November, 1955 — 2.30-5.30 p.m.

Candidates are required to answer FIVE questions only

1.

Emitters of the oxide coated, pure tungsten and thoriated tungsten types have widely differing characteristics. Define these differences, and show from them the fields of application to which each of these types of cathode is appropriate. Indicate in your answer the optimum operating temperatures for these emitters, and the effect of temperatures above and below the optimum; outline briefly a method by which these temperatures may be measured.

2.

Describe three of the following types of vacuum gauges and deduce, from the physical principles upon which they operate, the range of pressures which they may be used to measure, and their behaviour with respect to condensible vapours and the introduction of supplementary vapour pressures: —

(i) Pirani.
(ii) Knudsen.
(iii) MacLeod.
(iv) Philips.

3.

A considerable number of differing combinations of glass and metal may be used to produce vacuum seals. Enumerate these and describe the techniques used to ensure optimum mechanical and vacuum performances. Reference should be made to any necessary pre-treatment of metal surfaces and to the strain pattern of the finished seal. Describe briefly a technique by which the vacuum efficacy of metal/glass seals may be established.

4.

What are the effects of aluminizing the screens of cathode ray tubes. How is this process carried out on a production basis?

5.

Describe the principles of operation of secondary emission tubes, and outline the advantages to be gained from their use. Discuss the construction of one type of photo-multiplier tube.

6.

Explain the functioning of a junction semi-conductor. Describe one way in which the materials required for the manufacture of such a junction may be prepared to contain the appropriate degree of controlled impurity.

7.

What is meant by "post deflection acceleration" in a cathode ray tube, and in what way does the adoption of this principle effect the characteristics of an electrostatically deflected tube.

Deduce from electrostatic principles, with reference to an appropriate diagram, the influence of tube geometry upon deflection aberrations.

8.

Describe with the aid of sketches, two practical arrangements for the semi-automatic evacuation of direct viewing cathode ray television receiving tubes, and give details of a typical process schedule for this stage of their manufacture.

ANSWERS TO NUMERICAL QUESTIONS

Part I — Physics

1. 71·9 cm.
2. 5·53 cm.
3. $n\frac{V+v}{V}$ (V = velocity of sound)
4. (*a*) 39 gm.
   (*b*) 0·098 gm.
   (*c*) 1·43.
5. (*a*) 342 m/sec.
   (*c*) 90 cm, convex.
6. Rise of 4 e.s.u. of potential.
7. 39.
8. (*b*) (i) $R_s = 99{,}999\Omega$
   (ii) $R_p = \frac{1}{9999}\ \Omega$
9. (*a*) 8 min. approx.
   (*b*) 0·0003 gm/coulomb.
10. (*a*) 87·5 gauss.
    (*b*) 0·1 V.

Part II — Principles of Radio Engineering

1. 9 V.
3. 2·5 mH , 1·7 A, 72·5 V.
5. $g_m = 1\cdot5$ mA/V.
   $\mu = 15$.
   $g_m = 0\cdot45$ mA/V.
6. 62·5 V/cm.
8. 59·5 W, 58·4 W.
10. $\sigma =$ arc tan 0·0377
    $k = 11\cdot24$.

Part IIIa — Mathematics

1. (*a*) $x^2 - 12x + 61 = 0$.
   (*b*) $x = 3,\ y = -1$.
2. (*a*) $\frac{fk}{2C}$
   (*b*) $\frac{1+x}{(1-x)^2}$
3. (*a*) $D = 20 \log V_2/V_1 + 10 \log Z_1/Z_2 + 10 \log \cos\theta_2/\cos\theta_1$.
   54 db.
   (*b*) $\frac{3}{8} - \frac{1}{2}\cos 2x + \frac{1}{8}\cos 4x$.
4. (*a*) $1\sqrt{2\tan^{-1}b/a}$
   (*b*) (i) $2\cdot4 - 6\cdot2\,j$.
   (ii) $5 + 8\cdot66\,j$.
   (iii) $10\cdot04 + 17\cdot4\,j$.
5. (*a*) $\cos x$.
   (*b*) $\frac{4x-3}{6y-5}$
   (*c*) (i) $\frac{\cos\log x}{x}$
   (ii) $\frac{e^x(1-x)^2}{(1+x^2)^2}$
   (iii) $\sin^3 x$.
6. $V = 2$
   $x = 90°$ (a minimum)
   $x = 120°$ (a maximum)
7. (i) $\log x + \frac{h}{x} - \frac{h^2}{x^2} + \frac{h^3}{3x^3} - \ldots$
   (ii) $1 + x + \frac{x^2}{2!} - \frac{3x^4}{4!} + \ldots$
8. (i) $3\left(\frac{x^5}{5} + \frac{2x^3}{3} + x\right) + const.$
   (ii) $-\frac{\cos 4x}{8} - \frac{\cos 2x}{4} + const.$
   (iii) $\frac{1}{3}e^{(3x-5)} + const.$
   (iv) $\frac{1}{4}\sinh 2x - \frac{1}{2}x + const.$
   0·5493
9. $a = \pm 2$.

Answers to Numerical Questions—*continued.*

Part IIIb—Advanced Radio Engineering

1. (i) 320 Ω.
(ii) 10·7.

3. (i) Maximum at 1·95 Mc/s.
Minimum at 1·05 Mc/s.
(ii) 345 pF.

4. 75 pF.

5. (i) 335-0-335 V.
(ii) 0·95 A.
(iii) 128°
(iv) 148 V.

6. For bridged-T network :—
600 Ω, $66\frac{2}{3}$ Ω, 5,400 Ω.
For π-network :—
2970 Ω, $733\frac{1}{3}$ Ω.

Part IV — Radio Reception

1. 3·8 volts/kc/s.

2. 0·1%.

3. 0·209.

4. 13·6 c/s.

5. 28·9 db, 17·9 db.

7. 0·0279.

Part IV — Electronic Measurements

2. $L_{min} = 1{\cdot}01$ mH.
$L_{max} = 5{\cdot}5$ H.

4. 14·5 db, 10·2 db.

8. 24·4 pF ; 4·1 mH.

Part IV—Radio Transmission

1. 63%, 59·9 kW.

3. 1·3 ohm.

4. From 30% to 47·5% modulation.

6. (*a*) Star connected:
Line Current = 10 A.
Input Power = 5·7 kW.
Power Factor = 0·832.
(*b*) Delta connected:
Line Current = 30 A.
Input Power = 17·3 kW.
Power Factor = 0·832.

7. (*a*) 178 Amps r.m.s., (252 A peak).
(*b*) 14140 Volts r.m.s., (20,000 V peak).
(*c*) 25.

8. Shunt capacitance = 1187 pF.
Series Inductance = 14·6 μH.

9. Parallel conductance 5·68 millimhos.
Parallel susceptance $+j2{\cdot}84$ millimhos.

Part IV—Television

1. 1·1 cm.

3. 50 pF.

5. Pos. Black = 0·08.
Neg. Black = 0.54.
Pos. White = 0·85.
Neg. White = 0·13.

Part IV—Audio Frequency Engineering

2. Z_1: 4·852 mH, 0·0495 μF.
$Z_2/2$: 0·01016 μF.

5. —16·48 db.

6. 0·07.

8. 872 c/s.

REGULATIONS GOVERNING THE CONDUCT OF EXAMINATIONS

(Revised July, 1949)

Candidates are requested to note carefully the following instructions

1. Answer books, ink, blotting paper and log tables will be supplied at the examination, but each Candidate should provide himself with a pen and a ruler. Slide rules may be brought to the examination.

2. Candidates must keep a note of their number, which **must** be on the front page of each answer book used.

The Name of the Candidate must NOT appear anywhere on the Examination Papers, either on the headings or in the answers to the questions.

3. The Presiding Officer shall have power to discontinue the examination of any Candidate who may misconduct himself.

4. No Candidate will be allowed to communicate with, receive assistance from or copy from the paper of another. If this rule is infringed, the name of the person will be struck off the list of Candidates.

5. Candidates must **not** retain **any printed or manuscript paper or book** during the examination and must leave same with Presiding Officer before the hour of commencement of the examination. Any Candidate infringing this rule or consulting any printed or manuscript paper or book during his examination will be disqualified.

6. Each Candidate must write his answers legibly and must commence **each answer on a fresh page headed by his examination number and the number of the question.** Rough calculations (if any) should be carefully crossed out. No part of any paper is to be torn off. Scrap paper will **not** be allowed.

7. **Candidates' examination work must show evidence of a good general education. Marks may be deducted for defective writing, spelling, composition or grammar.**

8. After the examination has commenced no Candidate is to leave the room (without permission) until he has handed in his answers to the Presiding Officer. Any Candidate who leaves the room without permission will not be allowed to return.

9. When the Presiding Officer has declared the period allowed for examination over, Candidates must immediately cease writing.

10. Candidates may retain the question papers, except when requested to return them by the Presiding Officer.

11. The cost of the examination at all centres is defrayed by the British Institution of Radio Engineers.

12. Each Candidate will be informed by post, usually within two months of the date of the examination, whether he has passed or failed. No other information will be given.

13. Terms and symbols in examination answers should comply with the British Standard 204: 1943 and British Standard 530: 1948 and their supplements. The latter is out of print, but there is a copy in the Institution's Library.

14. Smoking will not be permitted in the Examination Room.

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