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The British Institution of Radio Engineers

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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. 8 AUGUST, 1955

NOTICE OF THE THIRTIETH ANNUAL GENERAL MEETING

NOTICE IS HEREBY GIVEN that the THIRTIETH ANNUAL GENERAL MEETING (the twenty-second since Incorporation) of the Institution will be held on WEDNESDAY, OCTOBER 26th, 1955, at 6 p.m., at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1.

AGENDA

1. **To confirm the Minutes of the 29th Annual General Meeting held on October 27th, 1954.** (Reported on pages 509-512 of Volume 14 of the *Journal* dated November 1954.)
2. **To receive the Annual Report of the General Council.** (To be published in the September 1955 *Journal*.)
3. **To elect the President.**

The Council is unanimous in recommending the re-election of Rear-Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O., as President of the Institution for the year 1955-56.

4. **To elect the Vice-Presidents of the Institution.**

The Council unanimously recommends the re-election of George A. Marriott, B.A.(CANTAB.), Leslie H. Paddle, John L. Thompson, and Professor E. E. Zepler, PH.D.

5. **To elect the General Council.**

The retiring members of the Council are:—

S. R. Chapman, M.SC. (*Member*)	Professor E. Williams, PH.D., B.ENG. (*Member*)
J. W. Ridgeway, O.B.E. (*Member*)	A. H. Whiteley, M.B.E. (*Companion*)

In addition, Lt.-Col. J. P. A. Martindale, B.A., B.SC. (*Associate Member*) retires on taking up an appointment in Australia.

Consequently, under Article 29, vacancies arise for ordinary members of Council as follows:—A maximum of three Members, one Honorary Member, one Associate Member, and one Companion.

In accordance with Article 32, the Council nominates:—

(*a*) Members for re-election: J. W. Ridgeway, O.B.E.; Professor E. Williams, PH.D., B.ENG.
(*b*) Member for election: Air Vice-Marshal C. P. Brown, C.B., C.B.E., D.F.C.
(*c*) Associate Member for election: Ronald N. Lord, M.A. (OXON.).
(*d*) Companion for re-election: A. H. Whiteley, M.B.E.

Any member who wishes to nominate a member or members for election must deliver such nomination in writing to the Secretary, together with the written consent of such person or persons to accept office if elected, not later than September 14th, 1955. Such nomination must be supported by not less than 10 corporate members.

6. **To elect the Honorary Treasurer.**

The Council unanimously recommends the re-election of Mr. G. A. Taylor (Member).

7. **To receive the Auditors' Report, Accounts and Balance Sheets for the year ended March 31st, 1955.**

The Accounts for the General and other Funds of the Institution will be published in the September *Journal*.

8. **To appoint Auditors.**

Council recommends the reappointment of Gladstone, Jenkins & Co., 42 Bedford Avenue, London, W.C.1.

9. **To appoint Solicitors.**

Council recommends the reappointment of Braund & Hill, 6 Grays Inn Square, London, W.C.1.

10. **Awards to Premium and Prize Winners.**
11. **Any other business.** (*Notice of any other business must reach the Secretary 40 days before the meeting.*)

(*Members unable to attend the Annual General Meeting are urged to appoint a proxy.*)

NOTICES

Cambridge Oversea School Certificate Examinations

Universities in the United Kingdom now base their entrance requirements on the G.C.E. The Oversea School Certificate examination conducted by the University of Cambridge is also acceptable on the basis of a credit pass being equivalent to a pass of ordinary level in the General Certificate of Education. Similarly, a pass in a principal subject in the Higher School Certificate is equivalent to a pass at Advanced level.

The Cambridge Oversea School Certificate is also accepted by the Engineering Joint Examinations Board as an exempting qualification from the Common Preliminary Examination, provided passes are obtained in five subjects with at least three at credit level. The Institution requires success in, or exemption from, the Common Preliminary Examination as a pre-requisite for Student registration.

Over 24,000 candidates sit the Cambridge Oversea School Certificate examination annually.

British Nuclear Energy Conference

An organization to be known as the British Nuclear Energy Conference has been formed by the Institutions of Civil, Mechanical, Electrical and Chemical Engineers and the Institute of Physics. Its affairs will be managed by a board consisting of three representatives from each society. The chairman is Sir Christopher Hinton and the secretary is Mr. Alexander McDonald, Institution of Civil Engineers, Great George Street, London, S.W.1.

Among its functions will be the presentation of papers on nuclear energy, publication of a quarterly journal, and the promotion of national and international meetings.

The expenses of the conference will be initially met by the Societies. The inaugural meeting will be held in the autumn, when a symposium of lectures will be delivered.

Indian Radio Industry

A panel for the radio and electronic equipment industry has recently been set up by the Indian Government to ensure the planned expansion of the industry under the second Five-Year Plan. The panel's main function will be to suggest measures for increasing production capacity and to advise on matters concerning future planning and rationalization.

Royal Garden Party

The President of the Institution, Rear-Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O., and Mr. G. D. Clifford, General Secretary, had the honour of invitations to the Royal Garden Parties held at Buckingham Palace last month.

Mr. R. H. Garner

Mr. R. H. Garner, B.SC. (Associate Member), who for the past seven years has been Principal of the Burnbank School of Engineering, Lanarkshire, has recently been appointed Principal of Coatbridge Technical College.

Formerly Honorary Secretary of the Scottish Section of the Institution, Mr. Garner has for the past year served as Chairman of this Section. A fuller account of his career was published on page 302 of the June 1953 *Journal*.

Band III Television Development

It has already been announced in the *Journal* that the temporary London transmitter of the Independent Television Authority is to be sited at Beaulieu Heights, Croydon, and it has now been confirmed that high-power test transmissions will commence during the first half of September, and regular service will begin on Thursday, the 22nd September. Low power tests for assessing the service area and to help industry have been undertaken for the past few months.

Details have recently been given of the sites for further I.T.A. stations: the Midlands station will be near Lichfield and that for Lancashire near Bolton. The Authority has come to the conclusion that it will be impossible to cover the whole of the north of England by a single central station and, accordingly, a site is being sought for a Yorkshire station which will probably be near Halifax. The time scheduled for the opening of these three stations is, respectively, the end of 1955, spring and autumn 1956.

The London and Manchester transmissions will be in channel 9 (approximately 191 to 195 Mc/s) and that for the Midlands in channel 8 (approximately 186 to 190 Mc/s); the Yorkshire frequency has not yet been announced. All transmissions will be vertically polarized and the effective radiated powers will most probably be 100 kW, subsequently increased to about 200 kW. Interconnections between studios and transmitters will be largely by microwave link.

A SURVEY OF TUNER DESIGNS FOR MULTI-CHANNEL TELEVISION RECEPTION*

by

D. J. Fewings, B.Sc.† and S. L. Fife (Associate Member)‡

Read before the Institution in London on January 26th, 1955. Chairman: Mr. E. G. Hamer, B.Sc. Previously presented before a meeting of the Merseyside Section.

SUMMARY

Channel availability for national television systems is stated and an historical outline given of design development for multi-channel reception in the U.S.A. The survey includes those designs of British, American and European origin which the authors have had the opportunity of investigating and for which the paper includes performance data. Chief emphasis is placed on a rotary coil turret design first developed in America, which has proved to be the most flexible and versatile tuner examined. Effects of receiver noise governing first stage design are considered and aerial noise over the spectrum is calculated to decide the minimum required noise factor for each channel when receiver noise becomes equal to aerial noise. The conclusions are that this condition is obtained with a receiver noise factor of 22 db at 40 Mc/s decreasing to 3 db at 220 Mc/s. The importance of these considerations are emphasized for fringe area reception. The immediate problem of enabling existing single channel receivers to operate for multi-channel reception is discussed. A solution considered to be the most successful is described in which the double superheterodyne system is avoided and installation made possible without a soldering operation; the tuner provides an output at the receiver i.f. and is connected in place of the original r.f. stages. The future requirements for ultra-high frequency multi-channel reception in the United Kingdom are discussed, and tuner designs incorporating lumped and distributed tuning elements are examined.

1. Introduction

The progressive development of a national television system is towards establishing a plurality of programmes, requiring individual selection. The economics for such programming are controversial, while the methods of providing for reception are equally stimulating to discussion.

The first question is not relevant to this paper and it suffices to state that this country is in part to be served with an alternative programme. This begins the era of multi-channel television reception in the United Kingdom and this paper is an examination of some available methods of incorporating the facility in a domestic receiver.

The international frequency bands available for national channels are shown in Table 1, while Table 2 shows how these bands have been utilized for three accepted television systems.

Table 1

International Frequency Bands

Band	From		To	
Band I.	41 Mc/s	to	68 Mc/s	V.H.F.
„ II.	87.5 „	„	100 „	V.H.F.
„ III.	174 „	„	216 „	V.H.F.
„ IV.	470 „	„	585 „	U.H.F.
„ V.	610 „	„	950 „	U.H.F.

A Television Advisory Committee was appointed by the Postmaster-General to inquire into the use of the bands for the expansion of the television service in this country, possibly by using the channels indicated in the first section of Table 2. Its findings are contained in a published report.[1]

The Federal Communications Committee (F.C.C.), is the frequency allocating authority in the U.S.A. and protects the eighty-two channels allocated to television in that country.

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* Manuscript first received January 4th, 1955, and in final form on April 21st, 1955. (Paper No. 324.)

† Marconi's Wireless Telegraph Co. Ltd., Baddow Research Laboratories, Chelmsford, Essex.

‡ The English Electric Co. Ltd., East Lancashire Road, Liverpool 16.

U.D.C. No. 621.397.61.029.62.

The Comité Consultatif International des Radiocommunications (C.C.I.R.) is chiefly associated with the 625-lines system, and with the channel recommendations given in the last section of Table 2.

2. Historical Development

Hitherto it has been possible to make British receivers to cover the five B.B.C. channels either by plug-in coils or by relatively simple switching over band I. Now, however, there is an immediate need to cover band III, and possible future u.h.f. channels in bands IV and V.

The problem is a new one for us, and for the best solution it is obvious that we should be guided by the experience of manufacturers in the U.S.A. who for years past have had to cope with multi-channel reception on a scale which we are not likely to reach for a very long time. There are today some 380 television stations operating in the United States and a further 470 are either under construction or pending. These stations are accommodated in the eighty-two television channels, which occupy approximately 500 Mc/s of the spectrum.

That the development was not simple is clear from the many and varied approaches made in the early stages. Outstanding among them was a tuner which covered the 13 channels of bands I and III by switching incremental inductances into the aerial, mixer grid and oscillator tuned circuits which were in the form of tuned lines. The success of this method was the result of great ingenuity in switch design which alone enabled the device to be mass produced. The complexity of the product would discourage any manufacturer not specially equipped for switch making. However, since tuners now appear to be regarded mainly as specialist components to be bought in, manufacturing difficulty will not worry the set makers. This type of tuner, using modern circuits, is still popular in the U.S.A. and it is understood that a British manufacturer is shortly to enter the market with a similar tuner.

In another successfully marketed tuner three single layer coils wound on a single rotable shaft were varied in inductance by the movement of contacts pressing on the coils as the shaft was rotated; ganging and tracking was relatively

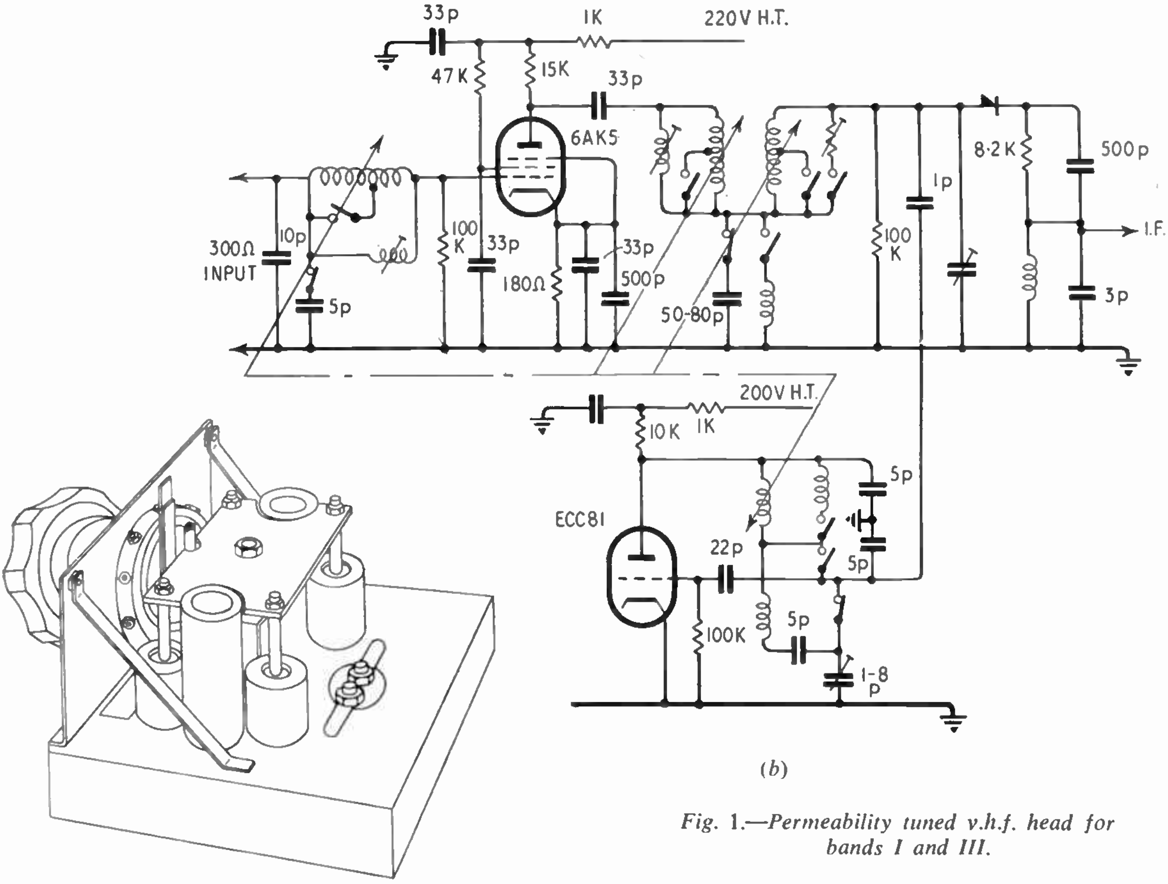
Table 2

Multi-Channel Television Frequencies

BRITISH				**F.C.C.**				**C.C.I.R.**			
405 *Lines Intercarrier* 3·5 *Mc/s*				525 *Lines Intercarrier* 4·5 *Mc/s*				625 *Lines Intercarrier* 5·5 *Mc/s*			
Channel	Vision Carrier (Mc/s)	Sound Carrier (Mc/s)	Local Osc.* (Mc/s)	Channel	Vision Carrier (Mc/s)	Sound Carrier (Mc/s)	Local Osc.* (Mc/s)	Channel	Vision Carrier (Mc/s)	Sound Carrier (Mc/s)	Local Osc.* (Mc/s)
1	45·00	41·5	79·65	2	55·25	59·75	101	1	41·25	46·75	80·15
2	51·75	48·25	86·4	3	61·25	65·75	107	2	48·25	53·75	87·15
3	56·75	53·25	91·4	4	67·25	71·75	113	3	55·25	60·75	94·15
4	61·75	58·25	96·4	5	77·25	81·75	123	4	62·25	67·75	101·15
5	66·75	63·25	101·4	6	83·25	87·75	129	5	175·25	180·75	214·15
6†	179·75	176·25	214·4	7	175·25	179·75	221	6	182·25	187·75	221·15
7†	184·75	181·25	219·4	8	181·25	185·75	227	7	189·25	194·75	228·15
8	189·75	186·25	224·4	9	187·25	191·75	233	8	196·25	201·75	235·15
9	194·75	191·25	229·4	10	193·25	197·75	239	9	203·25	208·75	242·15
10†	199·75	196·25	234·4	11	199·25	203·75	245	10	210·25	215·75	249·15
11†	204·75	201·25	239·4	12	205·25	209·75	251				
12†	209·75	206·25	244·4	13	211·25	215·75	257				
13†	214·75	211·25	249·4	Seventy u.h.f. channels 14 to 83							
				14	471·25	475·75	517				
				Adjacent channel intervals of 1·5Mc/s							
				83	885·25	889·75	931				

* Local oscillator frequency for recommended intermediate frequency.

† These channels are not yet (July 1955) available for television use.



(*a*)

(*b*)

Fig. 1.—Permeability tuned v.h.f. head for bands I and III.

easy and the whole tuner was attractively simple. Needless to say, great care had to be taken in the choice of contact materials in order to avoid the contact noise inherent in such a device. Noise-free operation was claimed for the tuner and indeed it must have been adequately so since it was used in large quantities and a version of it has been developed to cover the u.h.f. bands.

As far as the authors are aware, no successful permeability tuner was ever marketed in the U.S.A. although the principle is attractive. In early experiments by the authors an experimental tuner using this principle was made whose electrical performance compared favourably with that of any tuner of the pre-cascode era. It comprised a grounded cathode pentode r.f. stage, triode oscillator and crystal mixer with a bandpass circuit between the r.f. stage anode and the mixer. The bands I and III were covered in two switched ranges but only one set of four coil-formers was used, the upper band frequencies being achieved by taps on the lower band coils. The slugs were attached to a horizontal plate which was moved vertically by a cam. The cam was driven through a wafer-type click mechanism and had 12 adjusting screws and locknuts whereby each channel could be individually adjusted. Switching between channels 6 and 7 was accomplished by a wafer operated by means of a toggle driven by the channel selecting cam. Fig. 1a shows a sketch of the tuner and Fig. 1b its circuit. Noise factors varied over the range from 7db to 14db. The weakness of the device lay in its mechanics, the resetting accuracy being but barely adequate. Permeability tuning, to be successful, needs rigid and accurate mechanical design which tends to be expensive and probably accounts for its unpopularity. Notwithstanding this, a British manufacturer is now producing a tuner covering bands I and III using this principle and by making it continuously tunable, has avoided the difficulties that detent mechanisms introduce. In this tuner, tuning over band III is accomplished through a front control which, at one end of its travel, operates a Geneva mechanism which switches in a completely separate band I tuner, normally pre-set to the local station. Core movement on band I is accomplished by two spring loaded cams, and on band III by a double rack and pinion.

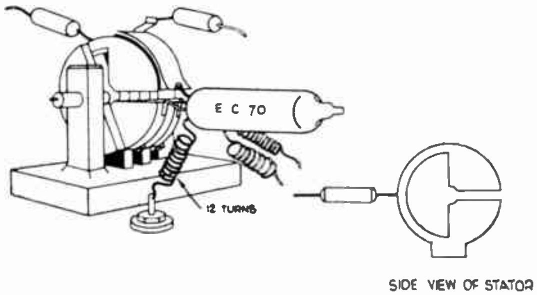


Fig. 2.—Butterfly tuner.

The coming of television on the u.h.f. bands in the U.S.A. led to considerable experimental activity on u.h.f. adaptors and converters. Among them were the so-called "butterfly" tuners in which inductance and capacitance were simultaneously varied to enable wide ranges to be covered. Fig. 2 shows a sketch of an experimental u.h.f. oscillator in which this principle was used. An EC70 valve was employed and the range covered 400 to 820 Mc/s. It was found difficult to achieve the wide range of frequency required without extremely close spacing of the tuning elements, which involved great accuracy of workmanship and also led to poor thermal stability of the oscillator. Other experimenters used various mechanical devices for varying small inductances but few of these emerged from the laboratory. The difficulties involved in making a continuously variable u.h.f. tuner probably had a major part in the popularization of the turret type v.h.f. tuner which could readily be modified to receive any required u.h.f. transmission simply by removing an unused v.h.f. coil strip from the turret and substituting a u.h.f. strip. An American company have now taken the logical step forward and have produced a turret in which 12 positions accommodate channels 2-13 and 4 positions which between them cover the whole u.h.f. range, i.e. channels 14-83.

Another American company, which pioneered the rotary turret, have also guided their development towards this end, and now market an eighty-two channel turret tuner with positive visual identification of each channel. These two tuners will be examined later.

It would appear that the turret tuner is the type most favoured at present in America, though the switched incremental inductance type is challenging strongly. There appears to be some dealer resistance to changing and adjusting u.h.f. turret strips, and very recently a continuously variable u.h.f. tuner intended for use with a separate switched v.h.f. tuner has been introduced. This u.h.f. tuner has exceptional merit from a manufacturing point of view, and will be described later.

3. Noise Considerations and the R.F. Amplifier

Noise is an important factor in assessing receiver performance, particularly for operation above 100 Mc/s, when cosmic noise radiation is of low intensity and receiver noise assumes first importance.[2]

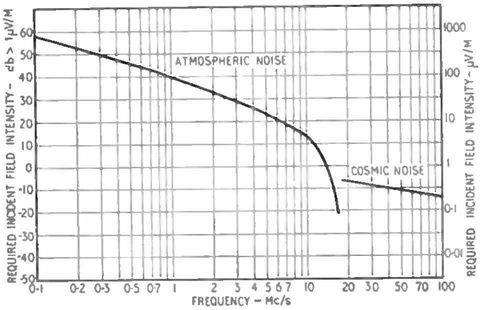


Fig. 3.—Atmospheric/cosmic noise distribution.

Figure 3 relates to the minimum required field strength at the aerial of a communications receiver having a 6-kc/s bandwidth for a 15-db signal/noise ratio in the presence of atmospheric and cosmic noise. It is seen that at 40 Mc/s, the start of the television band I, the intensity of atmospheric noise is negligible and cosmic noise predominates. The principal source of the noise is concentrated in the Sagittarius region and the noise voltage at the aerial terminals of a television receiver from a directional aerial will vary from hour to hour and day to day. The cosmic noise power at the aerial terminals is proportional to the receiver bandwidth, as also is the noise power available from the input resistance of the receiver. The required incident field strength for television reception therefore considerably exceeds that shown in Figure 3.

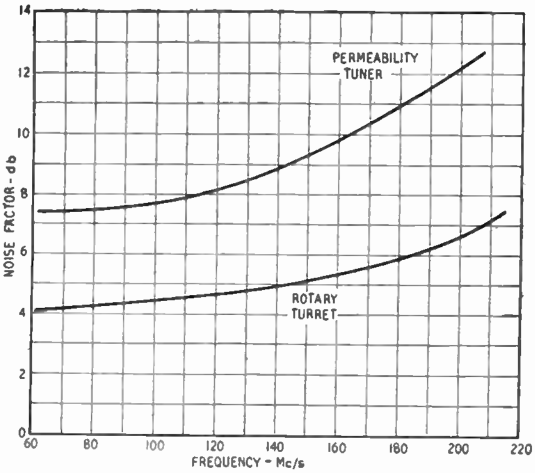


Fig. 4.—Typical noise factor curves.

Receiver noise is chiefly determined by first stage noise, which when amplified appears on both picture modulation and synchronizing pulses to become evident in the reproduction by broken line structure and line tearing. Typical noise factor curves are shown in Figure 4. Consideration of first-stage design, then, is directed to obtaining a high signal/noise ratio. High gain in itself is of little use when excessive noise level does not permit the operation of the receiver at its maximum gain.

It can be argued that in the case of a tuner to operate below 100 Mc/s, i.e. in band I, first-stage noise is not of prime importance, owing to the high intensity of cosmic noise over the television channel frequencies in this range, and a grounded-cathode pentode would be a suitable choice to secure high gain. With cosmic noise decreasing with the square-root of the channel frequency, operation in band III and the higher F.C.C. and C.C.I.R. channels requires first stage noise to be restricted and consideration given to the use of low noise triodes.

For stable operation at v.h.f. the grounded-grid triode is a possibility, but it has an undesirable low input impedance and characteristics which do not allow a.g.c. to be applied. A second choice is the cascode circuit* by Wallman,[3] which has a high input impedance but its frequency selective neutralizing circuit puts it at a disadvantage for multi-channel reception, it being desirable in a television tuner that neutralization should be independent of frequency.

4. The Rotary Coil Turret

A recently developed twin triode r.f. amplifier is identified as a driven-grounded-grid* and is incorporated in a turret tuner of an American company (Fig. 5). The American 6BQ7 valve first found commercial use in the switch type tuner[4] and a similar valve is now manufactured in this country. The two triodes are contained in the one envelope and are series connected to h.t. so that equal anode currents pass in each. The advantages obtained by this arrangement as against the conventional a.c.-coupled cascode will be examined later.

A high input impedance is secured by use of the grounded-cathode triode (termed the driver), and this allows a voltage gain over the aerial transformer. Neutralization of this first triode is effected by a capacitive bridge comprising 3pF and 3–9pF capacitors and the grid–cathode and grid–anode valve capacitances. The bridge is shown in Fig. 6 with the variable capacitor pre-set for the whole channel coverage, balance being substantially independent of frequency.

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* The authors use the following definitions in the paper:

Cascode Amplifier: Two a.c.-coupled triodes in cascade.

Driven-Grounded-Grid Amplifier: Two d.c.-coupled triodes in cascade (abbreviated d.g.g.).

Multi-Channel Adaptor: A multi-channel tuner head which provides an output at the receiver's intermediate frequency, and which is so connected that the single channel r.f. head of the receiver is dispensed with.

Multi-Channel Converter: A multi-channel head which provides an output at the receiver's normally received frequency involving a double superheterodyne process, i.e. a v.h.f. multi-channel tuner preceding a single channel receiver, or a u.h.f. head preceding a v.h.f. multi-channel tuner.

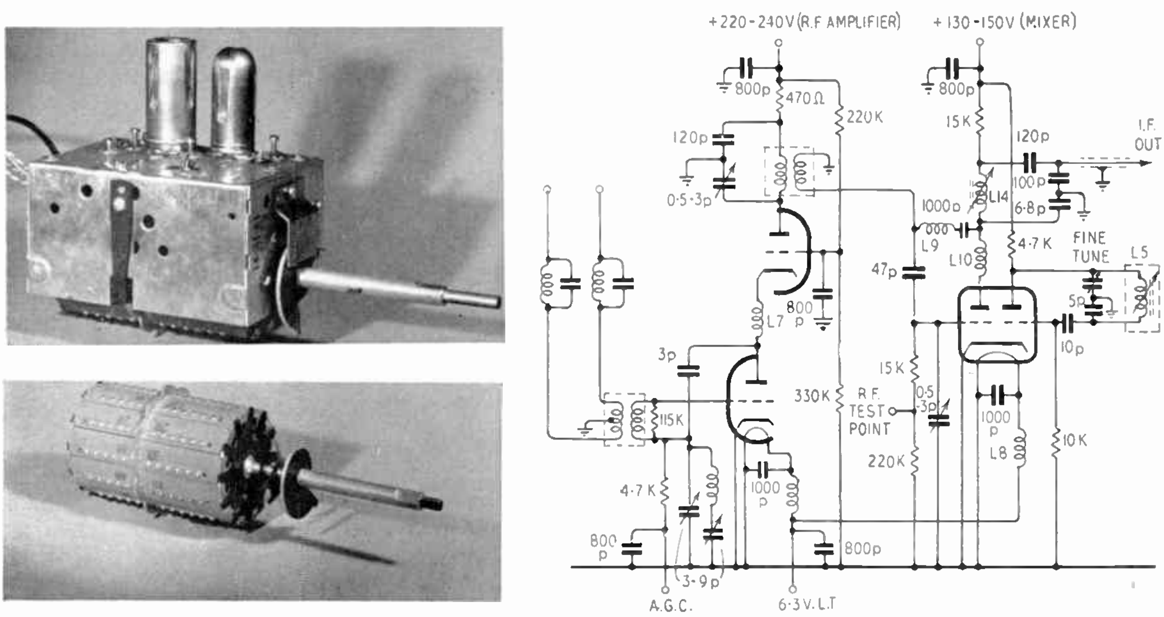


Fig. 5.—The rotary coil turret tuner.

Vision i.f. 45·75 Mc/s; Sound i.f. 41·25 Mc/s; R.F. amplifier anode current 5 mA (3 volts a.g.c.); Mixer anode current 12 mA.

The 15-kΩ resistor across the aerial transformer secondary terminals prevents excessive changes of input impedance with a.g.c., which is series applied, and also serves to maintain a closed grid circuit when switching between channels.

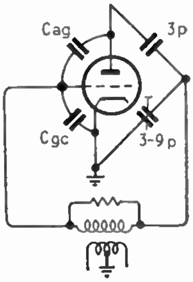
The second triode is grounded-grid connected and secures the advantages of reducing local oscillator radiation from the aerial more than is possible with a pentode. This fact is of particular importance in areas where several television channels are available.

Direct coupling between the two valves is by coil L7, which is series resonant with the grid–cathode valve capacitance of the grounded-grid section, and is sufficiently wide to be pre-tuned to the centre frequency of the higher channels, to give added gain over those channels. This "peaking" circuit is damped by the low input impedance of the second triode, given by $R_{(in)} = 1/g_m$. For the 6BQ7 and PCC84 $g_m = 6$mA/V, i.e. $R_{(in)} = 167$ ohms. This low impedance loading of the grounded-cathode triode would allow operation on the low channels without neutralization. However the bridge serves an additional function further to attenuate local oscillator injection into the aerial and contributes to improving noise factor.

Injection from the Colpitts-type local oscillator is effected by mutual inductance coupling

Fig. 6.

Neutralizing bridge of the driver in the driven-grounded-grid circuit.



between L5 and the secondary of the coupling transformer (L4). Fine tuning of the oscillator is available as a front control and has a measured range of 400 kc/s approximately on F.C.C. channel 2, increasing with frequency to 1160 kc/s on channel 13.

Drift compensation is effected partly by capacitive compensation with a negative temperature coefficient 5-pF capacitor and inductively by means of an aluminium core in the oscillator coil. Drift remains comfortably within the limits of ±150 kc/s, these limits being made in consideration of sound rejection in the vision i.f. circuits which generally include high-Q traps. Excessive oscillator drift causes sound modulation to appear on the picture. Drift measured on F.C.C. channel 2 of a tuner designed for an intermediate frequency of 25·75 Mc/s (vision), 21·25 Mc/s (sound) was 90 kc/s in a negative direction with good return to datum upon cooling. Drift on channel 12 (Fig. 7) was 80 kc/s in a positive direction followed by good compensation, with a further positive 80 kc/s change during cooling. The lower curve is of oven temperature.

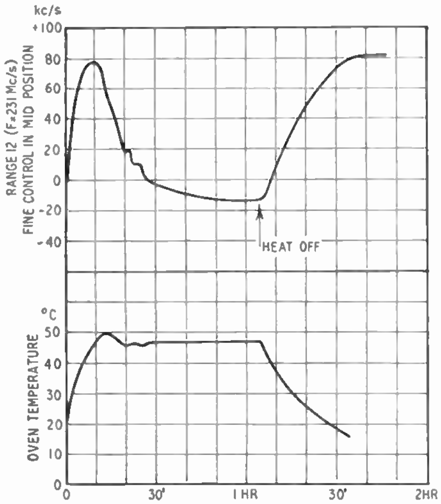


Fig. 7.—Local oscillator drift (channel 12) of the turret tuner.

The measured performance of the tuner is given in Table 3. It is interesting to compare with this performance that of a similar turret tuner, made up from a kit of parts supplied by a British manufacturer, which is given in Table 4.

4.1. *The Driven-Grounded-Grid Circuit*

Figure 8 is a plot of the mutual characteristic which was obtained from an early experimental valve (ECC84) which has since been superseded by the PCC84. Curve 1 is that of a single triode and curve 2 that obtained by direct-coupled series arrangement. It is seen that by operating the two triodes in series the grid base is extended with the long tail enabling smooth a.g.c. control The square-law curve reduces risk

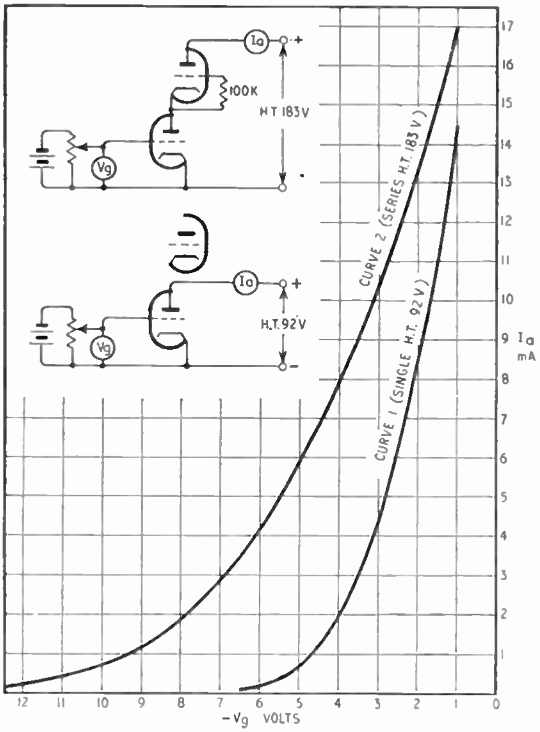


Fig. 8.—Mutual characteristics of the ECC84.

Table 3

Performance of American Turret Tuner

Channel (F.C.C.)	Noise Factor db	Voltage Gain +db	I.F. Rejection −db Vision	Sound	Image Rejection −db Mid-band	Skirt Gradient db/Mc/s L.F.	H.F.
4	5	39	58	54	≥60	7	4
7	6	38	48	>60	>60	6	5
13	6·5	41	>60	>60	>60	7	5

Table 4

Performance of British Turret Tuner

Channel (U.K.)	Noise Factor db	Voltage Gain +db	I.F. Rejection −db Mid-band	Image Rejection −db Mid-band	Skirt Gradient db/Mc/s L.F.	H.F.
3	4	44·5	40	60	9	7
9	7	34	50	60	5	3

of cross-modulation between the vision and sound signals, which is a real possibility with the sharp cut-off obtained with the single triode.

The equivalent circuit of the driven-grounded-grid (Fig. 9) depicts a negative step voltage ($-E_g$) applied to the first triode, with the generator voltage (μE_g) operating in the anode circuit with polarity as shown. A positive step voltage at the cathode of the second triode is equivalent to a negative one at the grid, producing a positive rise at the anode, so the generator voltage operating in the anode of the second triode is series aiding that of the first. The input signal to the second triode (μE_g) is reduced by the volts across the internal resistance of the first triode since it is common, and the effective input to the grounded grid becomes ($\mu E_g - i_a R_a$) volts.

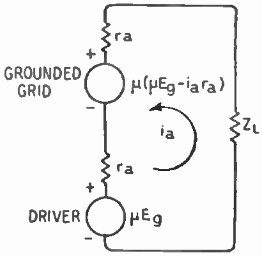


Fig. 9.
Equivalent circuit of the driven-grounded-grid amplifier.

The circuit equation is then:

$$\mu E_g + \mu(\mu E_g - i_a R_a) = i_a(2R_a + Z_L) \quad \ldots\ldots (1)$$

Solving for i_a,

$$i_a = \frac{(1+\mu)\,\mu E_g}{R_a(2+\mu) + Z_L} \quad \ldots\ldots (2)$$

Multiplying by $\dfrac{Z_L}{E_g}$,

$$\text{Gain} = \frac{\mu(1+\mu)}{\dfrac{R_a}{Z_L}(2+\mu) + 1} \quad \ldots\ldots (3)$$

The gain equation is comparable to the pentode gain ($g_m . Z_L$) and is identical to the conventional cascode gain. The additional merits previously noted, however, justify the necessity for a distinct identity being given to the new circuit.

4.2. *R.F. Amplifier/Mixer Coupling Methods*

A variety of couplings may be used between the r.f. amplifier and the mixer. Four possible methods are:

1. Double tuned transformer.
2. Double tuned circuits—top capacitance coupled.
3. Parallel single circuit.
4. Series single circuit.

The double tuned transformer is attractive when considering the steep response skirts obtained by its use with the consequent improvement of adjacent channel rejection, that is, the rejection of the sound signal of the next upper channel (U.K.) or of the next lower channel (F.C.C.). If this signal is present in any strength, a 1·5-Mc/s r.f. pattern can appear on the picture tube. The signal/noise ratio is also improved by the restricted bandwidth which the coupling affords. The tuning of the primary and secondary in a rotary turret tuner does present a difficulty with only one entry of the former open, since the other is blocked by the oscillator core. In the particular tuner described, the tuning of the primary and secondary coils of each channel is made by slight physical adjustment of the turns. A claim usually made for the double tuned transformer is the higher gain secured over that of a single circuit. This statement needs qualifying.

The gain-bandwidth product with the double tuned transformer is given by:

$$G\,\Delta f = \frac{g_m}{2\pi C}\cdot\frac{1}{2}\cdot\sqrt{y^2 + 2y - 1} \quad \ldots\ldots (4)$$

where C = tuning capacitance of each half in the double tuned circuit and the total capacitances of the single tuned circuit
Δf = bandwidth.
y = relative coefficient of coupling, i.e. ratio of coefficient of coupling to that of critical ($y = k/k_{(crit)}$)

The gain-bandwith product with a single parallel circuit is given by:

$$G\,\Delta f = \frac{g_m}{2\pi C} \quad \ldots\ldots (5)$$

Comparing the two equations it can be seen that even though the double tuned transformer divides up the capacitances to make C small, at critical coupling, i.e. when $y = 1$, the gain of both as obtained in practice are about equal. Only when overcoupling is used does an appreciably higher gain result. If C is ⅔rds of the single circuit capacitance and $y = 2$, for the same bandwidth the transformer stage has 6 db more gain than the single parallel tuned circuit. Overcoupling may be used between the r.f. amplifier and mixer and the "valley" in the response filled in by a single tuned circuit, i.e. the r.f. grid circuit, in preference to excessive resistance damping. Similar remarks apply to method (2) as for this double tuned transformer. With top coupling, Cc is required to be of small value only (i.e. 1-3 pF) for the desired bandpass response.

That part of the shunt capacitance C imposed on the parallel tuned coil by the input capacitance of the mixer, may be reduced by making Cc small, which will also reduce the effective resistance damping across the coil. The input resistance of the PCF80 at 200 Mc/s, for example, is approximately 625 ohms which, since it is shunted across the coil, causes Δf to be excessive. Although by making Cc small, attenuation is introduced in the coupling, an increase in stage gain is realised by the minimized input loading effects of the mixer on the tuning coil. The resultant resistive and capacitive shunt components across the coil from the mixer input loading of 600 ohms and 15pF, with a 10pF coupling capacitor, may be shown to be 3,750 ohms and 6pF respectively.

A series tuned circuit between amplifier and mixer effectively divides up the capacitances and is particularly useful for continuous range coverage by adjustable core. The input signal to the mixer is that developed across its input capacitance. With C_2 smaller than C_1 the gain-bandwidth product is slightly more than with the single parallel circuit as given by:

$$G \Delta f \simeq \frac{g_m}{2\pi C_2} \quad \ldots\ldots\ (6).$$

This form of coupling is used in the turret tuner of a British manufacturer. Whilst the gain with this coupling method is less than that obtained by use of a double transformer coupling, the method is attractive because of the alignment facilities incorporated in this particular tuner. A hollowed brass core tunes the local oscillator and this allows a core adjustment to be made for tuning the coupling coil of each channel, whereas the double tuned transformer coupling requires physical adjustment of turns spacing for tuning each channel. Although in production quantities the tuning required of the transformer windings can be made very small by maintaining close inspection on winding, actual experience of alignment by the methods of spacing turns is necessary to appreciate the facility which the series resonant circuit offers.

In another British design this difficulty has been overcome whilst the double tuned transformer coupling has been retained. This has been facilitated by positioning the oscillator and aerial coils radially in the turret, allowing entry to the tuning cores of the transformer primary and secondary through the front and rear of the turret.

4.3. *Local Oscillator Injection*

The methods of local oscillator injection by either mutual inductance or small capacitive coupling have each their own merits and have been discussed elsewhere, and in this type of tuner design both methods have been used. The coupling capacitor is common to all channels and with this fixed component the amount of oscillator injection varies over the channels.

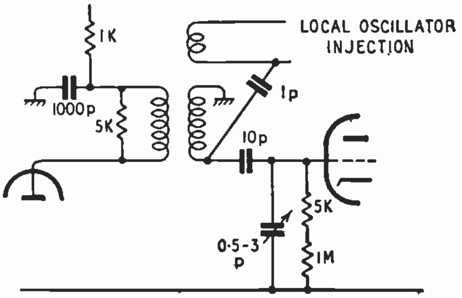


Fig. 10.—*Mixed coupling for local oscillator injection.*

However, with a series screen resistor and automatic grid bias, the conversion gain of the mixer can be maintained sensibly constant with different amplitudes of oscillator injection over the channels. A German manufactured tuner uses a mixed coupling as shown in Fig. 10. A combination of mutual inductance and capacitive injection is also used in an export model of a turret-type tuner of British manufacture. With close proximity of the oscillator and coupling coil, mutual inductance exists between the two, whilst the oscillator anode connection to the oscillator coil is extended by a single wire physically to touch, though insulated from the coupling coil. The capacitance between the lead and the coupling coil was measured to be 1·5pF on F.C.C. channel 5.

4.4. *Aerial Input*

The ideal aerial transformer would include a Faraday screen as shown in Fig. 11a, which would ensure inductive coupling only and remove risk of unbalancing capacitive currents. A balanced feeder would then be the obvious choice feeding from a balanced dipole aerial. The inclusion of a capacitive screen between the primary and secondary circuit would introduce production difficulties, but its omission is permissible since without it the secondary can be balanced sufficiently accurately for correct neutralization. While a balanced feeder would appear to be the obvious choice, it is often rejected for a co-axial type. One can only conclude that its continued use follows the era of the unbalanced tapped input coil, although the balanced feeder used between a balanced source and load obtains a number of merits.

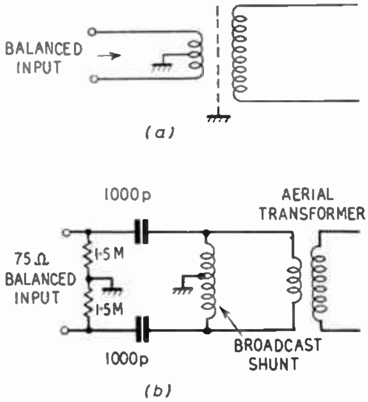


Fig. 11.—Aerial balanced input circuit.

The British Standards Specification on safety requirements in radio equipment (B.S.415) requires a discharge path to be provided for aerial static, and in Fig. 11b the two resistors provide for this. With this provision, risk of aerial static accumulating is lessened, but the specification for a.c./d.c. receivers requires isolating capacitors of 2·5 kV test inserted as shown. With this type of input it was found that cross-modulation could occur in the presence of powerful broadcast signals owing to the absence of a low impedance shunt path for medium and long wave signals. The centre-tapped coil of approximately 1·3 μH provides an adequate shunt without incurring mistuning of the aerial transformer or modifying tuner performance.

5. Alternative Cascode Coupling Method

In the r.f. amplifier of the tuner described (Fig. 5), the direct coupling between the triodes is effected by a peaking circuit resonant over the high channels. The heater chokes serve merely to minimize microphony due to variations of the heater–cathode capacitance.

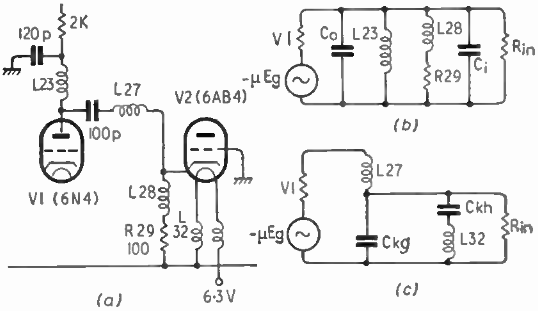


Fig. 12.—An "automatically tuned" cascode coupling circuit.

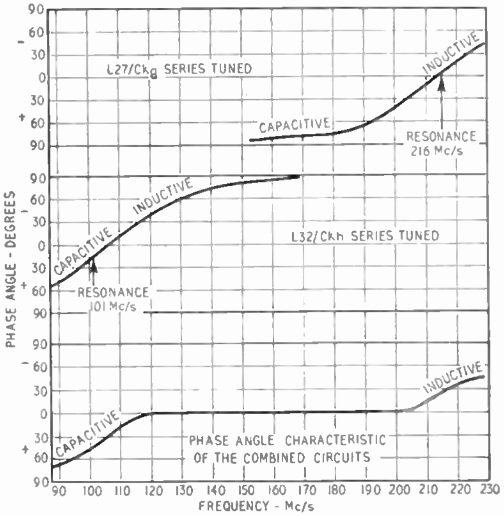


Fig. 13.—Reactance graphs of "automatically tuned" circuit.

A coupling method patented by an American company incorporates a low channel parallel peaking circuit, and an "automatic tuning" device over the high channels which uses a series peaking coil in combination with a series resonant heater circuit.[5] The method discards direct coupling between the triodes and reverts

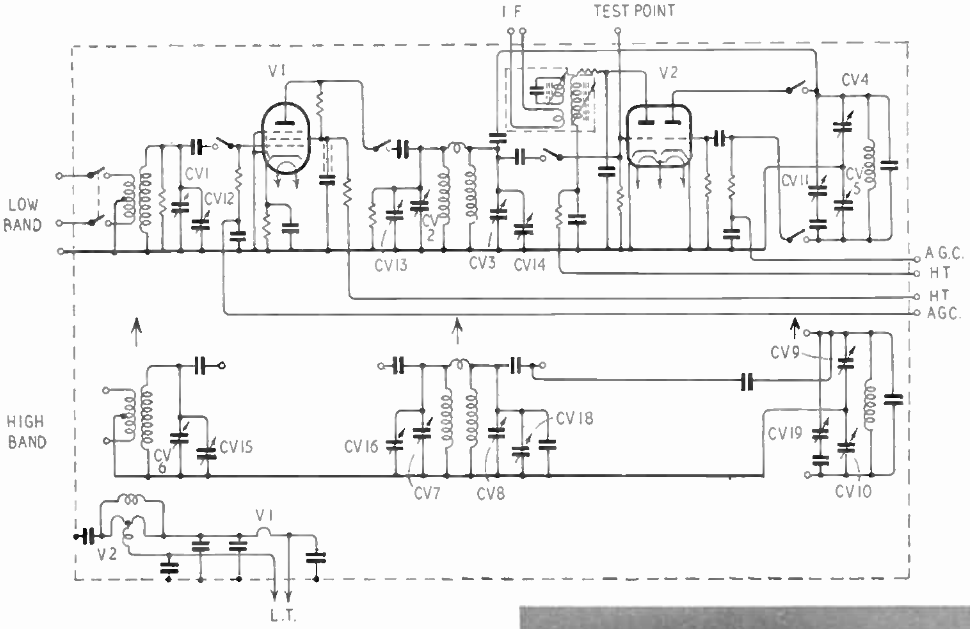
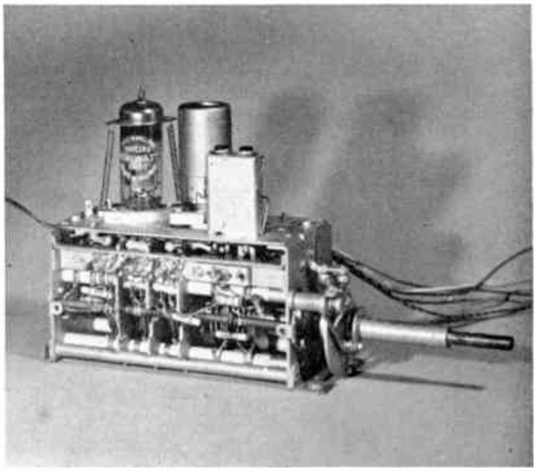


Fig. 14.—A v.h.f. capacitive tuner.

to the a.c.-coupled cascode arrangement. The chief features of the coupling are shown in Fig. 12a.

The equivalent circuit (Fig. 12b) over the low channels shows L23 and L28 connected in parallel to resonate with the capacitances at the centre frequency of F.C.C. channel 2; L23 is of greater inductance than L28. The reduction of circuit *Q* by the 100-ohm resistor ensures that parallel resonance "broadbands" over the low channels. The dynamic impedance of the L23-L28 circuit is greater than the input loading of the grounded-grid section, so that the determining load is the input impedance, making the exact frequency and components uncritical.

The equivalent circuit of Fig. 12c shows the small coil L27 in series resonance with Ckg whilst the heater coil L32 is series resonant with Ckh. As shown in the reactance graph of Fig. 13, L27 and Ckg resonate in channel 13 at 216 Mc/s, the circuit being capacitive over the high channels, whilst L32 and Ckh resonate in Channel 7 at 107 Mc/s and the circuit is then inductive over the high channels. The resultant reactance curve of the coupling shows resonance maintained over the high channels.



6. The Capacitive Tuner

Channel selection in this tuner of European manufacture (Fig. 14) is by an eight-gang brass capacitor which is used in a continuous rotation system with automatic indexing of the channels effected by a slotted disc on the capacitor shaft. The circuit is conventional with a grounded cathode pentode r.f. amplifier (EF80) and a twin triode mixer/oscillator (ECC81). For the F.C.C. standards an intermediate frequency of 25·1 Mc/s (vision) and 20·6 Mc/s (sound) is chosen.

The same coils are used for all low band channels and tuning from 55·25 Mc/s (channel 2) to 83·25 Mc/s (channel 5) in the F.C.C. low band is accomplished by CV1, CV2, CV3 and the split-stator CV4-CV5. For the high band channels from 175·25 Mc/s (channel 7) to 211·25 Mc/s (Channel 13) the coils and the associated components shown below the main circuit are switched in to replace the low channel circuits and tuning effected by the capacitors CV6, CV7, CV8, CV9-CV10 carried on the same spindle. Switching the low and high channel circuits is automatic between channels 6 and 7 and is effected by rotation of the selector spindle operating a cam coupled to a sliding type band-switch.

In the receiver this tuner is given a resilient mounting to prevent microphonic effects through plate vibration.

The measured performance of the capacitive tuner is given in Table 5.

Table 5

Performance of Capacitive Tuner

Channel (F.C.C.)	Noise Factor db	Voltage Gain +db	I.F. Rejection −db Vision	I.F. Rejection −db Sound	Image Rejection −db Mid-band	Skirt Gradient db/Mc/s L.F.	Skirt Gradient db/Mc/s H.F.
4	14	21	23	$>$ 45	$\gg$ 50	6	Adjacent Trap Action
7	15	14	39	$>$ 45	$\gg$ 50	4	
13	18	14	$>$ 45	$>$ 45	$\gg$ 50	5	

7. Switched Incremental Inductance Tuner

A British version of the switched incremental inductance type of tuner is in development and includes a driven grounded grid r.f. stage with a band-pass circuit between the r.f. stage and the mixer. Bands I and III are covered in 13 switched positions and a 14th position converts the tuner into an i.f. amplifier for a u.h.f. tuner.

Manufacturers' preliminary performance data are given in Table 6.

Table 6

Performance of Switched Incremental Inductance Tuner

Channel (U.K.)	Noise Factor db	Voltage Gain +db	I.F. Rejection −db Vision Sound	Image Rejection −db Mid-band
1	5·7	52	$>$ 40	$>$ 50
5	6·1	42	$>$ 40	$>$ 50
9	8·1	32	$>$ 40	$>$ 40

8. Frequency Response Characteristic

The bandpass response with acceptable tolerance limits is shown in Fig. 15; this relates to U.K. channels.

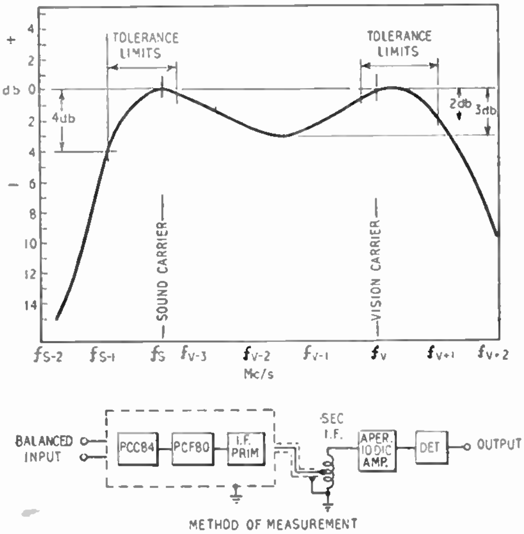


Fig. 15.—Typical r.f. bandpass response (with tolerance limits) for home channels.

The two tuners described were used in export receivers preceding four i.f. stages which were common for the amplification of the vision a.m. and the sound f.m. signals. This is the technique for intercarrier sound reception, which requires that at the vision detector the sound signal should be some 20 db below the vision signal level.[6] This amount of attenuation (dependent upon the relative vision and sound transmitter powers) is introduced by rejector traps, tuned to the sound i.f., which are generally incorporated in the common i.f. strip, but there is no reason why the r.f. tuner reponse should not be down at the sound r.f. and flat over the vision frequencies band.

9. Signal Balancing

For bands I and III operation, multi-channel tuners based on the design described will have a single 75-ohms aerial input. This suggests that a band I and III aerial will be combined in a cross-over network at a convenient point along the feeder run and a single feeder brought to the multi-channel tuner. For multi-channel reception a desired condition is equality of signal strength at the multi-channel tuner input. This may be done by the insertion of a resistive pad on the aerial side of the cross-over network, providing, of course, that the attenuated signal maintains a desired signal/noise ratio.

Generally a.g.c. will obviate the need for signal balancing, but the case might arise where an excessive signal strength difference exists between the channels received when the a.g.c. system would not prevent overload by the stronger signal. With this particular condition in view, the authors incorporated an automatic r.f. overload trip circuit[7] in a marketed receiver using a turret type tuner, which involved only minor circuit changes.

The overload trip device was a relay (250 ohms) which was series connected in the h.t. feed to two a.g.c. controlled stages, the driven-grounded grid r.f. amplifier of the multi-channel tuner and the first i.f. amplifier, so that they functioned as d.c. amplifiers in operating the relay. The armature operates a s.p.s.t. switch in the d.c. path of the cathode of the r.f. amplifier. With small signal inputs the relay is energized and the cathode circuit held closed. With increasing signal the relay current falls with increasing a.g.c. volts, until the relay de-energizes and the cathode is opened. Hunting of the relay does not occur due to the retentivity of the pole–armature magnetic path. The open cathode r.f. amplifier provides attenuation as follows:

Band I	Channel	1	... ...	52 db
	,,	5	... ...	54 db
Band III	,,	8	... ...	41 db

The swept receiver response on band I channels remains identical with both conditions of the cathode, whilst band III channels become slightly peaked at the vision carrier end of the response. Since the relay would normally be required to operate on band I channels only, this is of no consequence. For the tests only one suitable relay was available, and this required to be shunted by a 600-ohms resistor for the desired operating point. The circuit would undoubtedly operate better with three a.g.c.-controlled stages when the relay current gradient would be steeper and the setting-up tolerance less critical.

10. Adaptor Applications

The foregoing remarks relate to multi-channel tuners for operation in bands I and III and are applicable both as an integral feature of receiver design and for enabling existing band I receivers in the field to operate on band III channels also. The particular problems involved in the latter application merit brief examination.

It is desirable that a band I receiver should be readily made operative for band III also by attachment of the tuner, and that the operation should not involve any soldering or realignment. The double superheterodyne principle is at once suggested with the i.f. output of the tuner being at the band I receiver r.f. channel frequency and connected to its aerial terminals. The disadvantages of this system are:

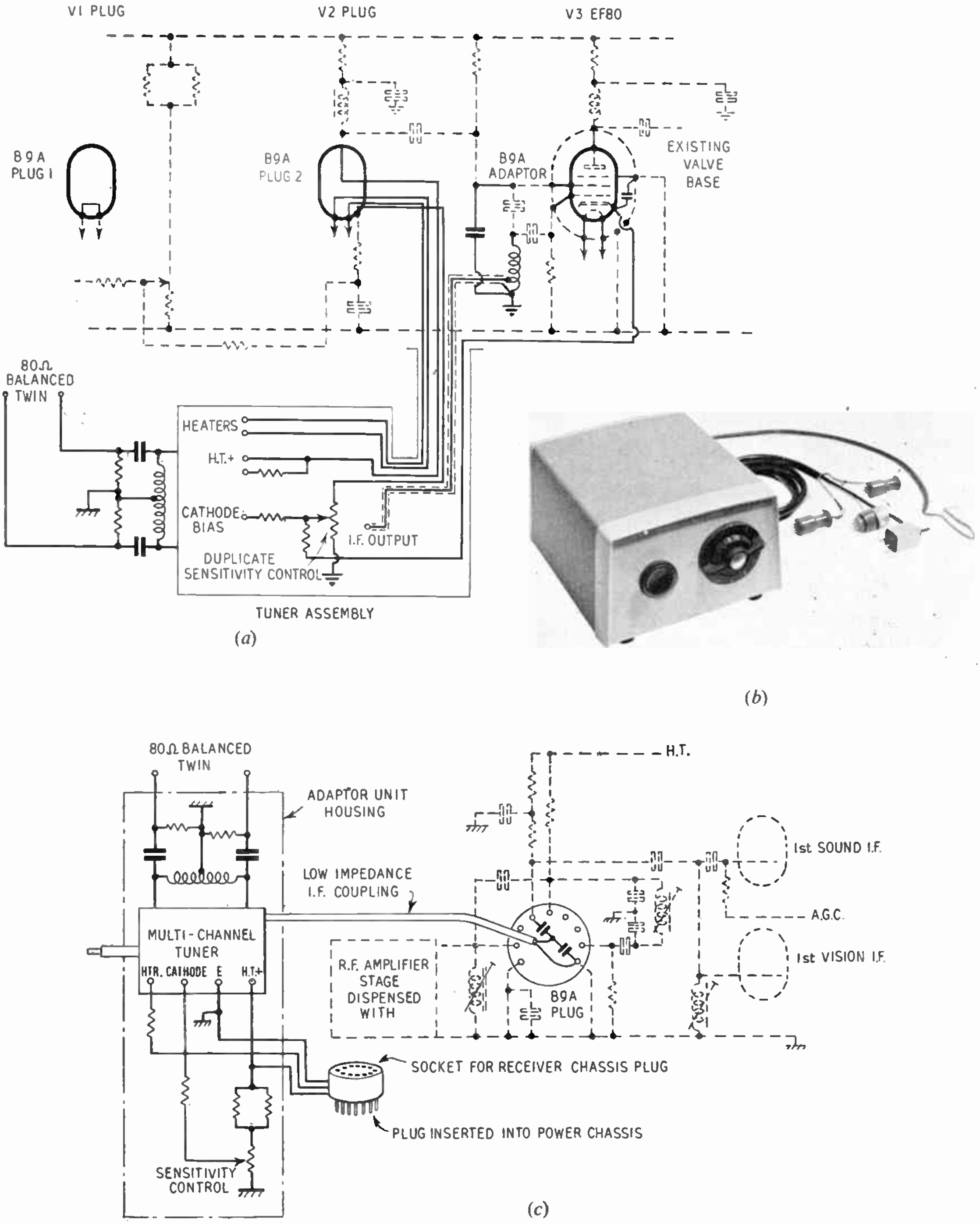
1. Direct break-through of band I transmission to receiver's front-end when converter is tuned for band III stations.
2. The multitudinous beats possible.

The difficulty of finding solutions to these two problems, lead to the conclusion that the double superheterodyne method is to be avoided.

A better solution is for the i.f. output of the adaptor to be at the receiver's i.f. and to connect to the first i.f. stage. The receiver's front-end then becomes superfluous. The authors have used this method successfully in two applications which were achieved by plug-in devices only.

The first receiver employed two r.f. amplifier stages and a pentode additive mixer. The mixer stage had a plug-in coil associated with it. This coil was removed and the socket utilized for plugging in the output from the adaptor, as shown in the circuit of Fig. 16a. Also shown is the modified form of this stage, which functions as the first i.f. amplifier, following the multi-channel tuner. Cathode bias is facilitated by the split valve base plug/socket.

The second receiver used an r.f. amplifier stage and a twin triode mixer, with all the coils of the r.f. section mounted on the underside of the chassis, so that it was not possible in this



(a)

(b)

(c)

Fig. 16.—Adaptor circuits enabling single channel receiver to operate for multi-channel reception.

case to utilize a coil socket. In Fig. 16c are shown the receiver's twin-triode mixer/oscillator base connections and the first i.f. circuit, and the method whereby the tuner output at the receiver's i.f. is connected by a valve base plug at the receiver's mixer socket. A capacitive impedance match is used between the low impedance tuner i.f. lead and the high impedance receiver i.f. input circuit. Conditions for correct impedance transformation is given by:—

$$\left(\frac{C_1}{C_2}\right)^2 = \frac{Z_2}{Z_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where Z_1 = impedance of tuner i.f. output (70Ω approx.)
Z_2 = impedance of receiver's i.f. input circuit (4kΩ)

C2 is made as large as possible while still retaining correct tuning of the i.f. secondary coil and this was found to be limited at 3pF with C1 then made 22 pF. A bandpass response is obtained over the i.f. primary (contained in the tuner) and the secondary coil, L10.

The power supplies for the tuner in both applications are taken from the receiver by plug terminations, in the first case from the unused r.f. valveholder by a B9A plug, and in the second from the power chassis multiway socket with a suitable plug/socket termination.

11. Choice of Intermediate Frequency

It is extremely desirable with national multichannel transmissions that a standard i.f. band be adopted to facilitate ease of investigating sources of interference and to obtain assurance that the band is made exclusive by the controlling frequency allocating authority. To this end the following have been recommended[8]:

Table 7

Recommended Intermediate Frequencies

System	Vision I.F. (Mc/s)	Sound I.F. (Mc/s)
British	34·65	38·15
F.C.C.	45·75	41·25
C.C.I.R.	38·9	33·4

One factor governing the choice of the above frequencies is the necessity to minimize i.f. harmonic feedback. This difficulty does not arise with band I channels in the U.K. whilst with reception of channel 8 the fifth i.f. harmonic falls within the r.f. channel (Fig. 17). However, the authors have experienced no interference from this source. With reception of F.C.C. channel 6 the second harmonic of the i.f. has been found troublesome in giving rise to "patterning" while the higher order harmonics have not been evident.

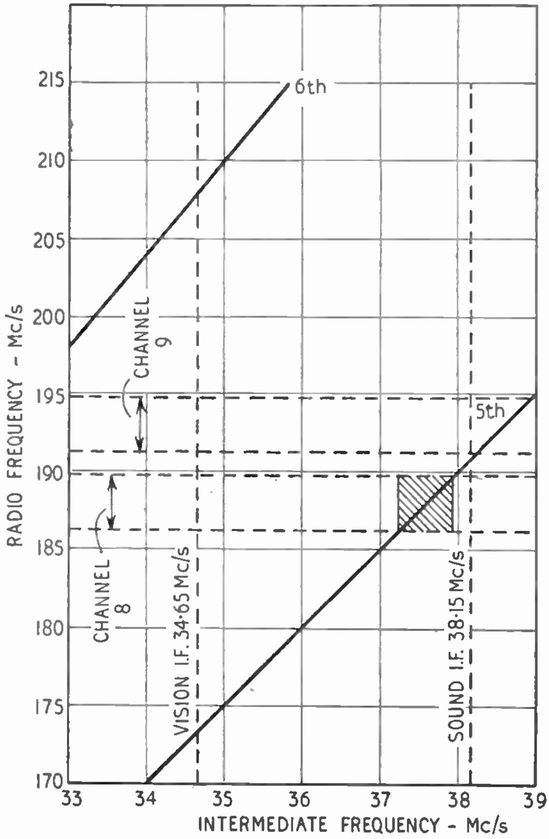


Fig. 17.—I.F. harmonic chart for band III.

One lesson from America which we in this country must not fail to learn is that multichannel television operation can greatly increase the interference problem if receiver local oscillator radiation is not adequately suppressed. One has only to examine the stringent regulations relating to this subject laid down by the F.C.C. to realize that this has been a major source of trouble in the United States which we should endeavour to avoid right from the start. To this end, the British Radio Equipment Manufacturers' Association has already made recommendations.[9]

12. Future Requirements

The progressive expansion of television in the country will eventually necessitate the use of the u.h.f. channels, whether for the introduction of a colour system or additional channels for monochrome transmissions. In the Television Advisory Committee report, the recommendation was made that in the first instance only every other channel in bands IV and V should be allocated to allow expansion of bandwidth if this proves a future requirement.

At the outset it is recognized that the u.h.f. head will be without amplification, since the cost of a suitable valve, at this time, is prohibitive for a domestic receiver. Attention immediately turns to maintaining a high Q in the pre-selector circuits compatible with bandwidth requirements of the channels. The u.h.f. head may be either a switched channel or a continuously tuned system. The choice is a debatable one and some points applicable to the introduction of u.h.f. into this country, affecting domestic receiver design, may be briefly stated as follows:—

1. Possible public preference for switch selection, i.e. by rotary turret or detent mechanism incorporated in a continuously tuned system.
2. Resetting accuracy of a switch system would need to be superior to that which suffices for a v.h.f. tuner.
3. A continuously tuned system would allow for the introduction of additional u.h.f. channels, and would avoid the necessity of "zoning" dispatched u.h.f. heads. With the advent of multi-channel u.h.f. television, the system would conserve production test time.
4. The ability of the public to tune correctly a continuous system is doubtful and must be carefully considered.

13. Switched U.H.F. Channels: Rotary Turret Methods

An early design of an American Company employed a brass casting in which the u.h.f. circuits were contained, comprising pre-selector circuits, crystal mixer, and local oscillator crystal multiplier. This was inserted in the rotary turret of the v.h.f. tuner and occupied one of the twelve channel positions. The block diagram (Fig. 18) shows the tuner function on v.h.f. and u.h.f.

On u.h.f. the driven-grounded-grid stage (r.f. amplifier at v.h.f.) and the triode (mixer at v.h.f.) are tuned i.f. amplifiers, and the triode oscillator frequency is selected as a harmonic of this by the crystal multiplier circuit.

The i.f. output of the u.h.f. head is coupled into the grid of the driven-grounded-grid amplifier by a pi filter section in which the first shunt capacitor and series coil is contained in the u.h.f. head, the second shunt capacitor being the input

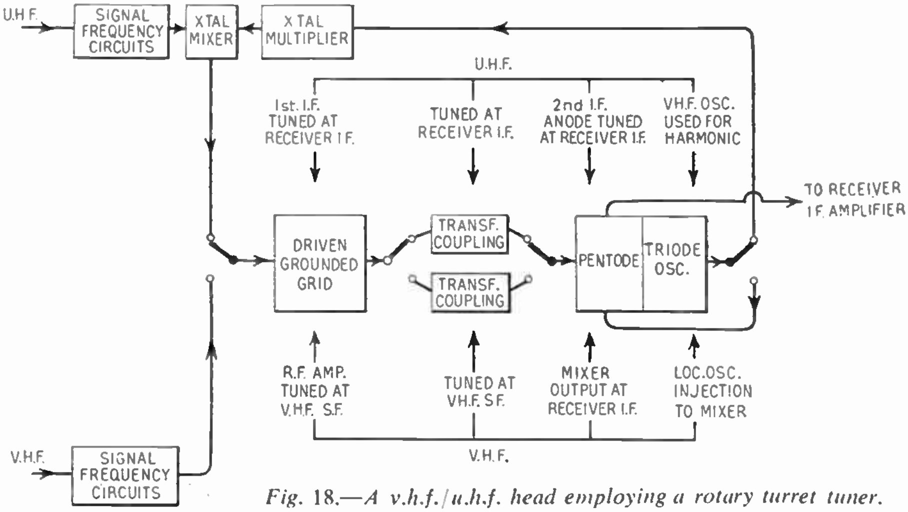


Fig. 18.—A v.h.f./u.h.f. head employing a rotary turret tuner.

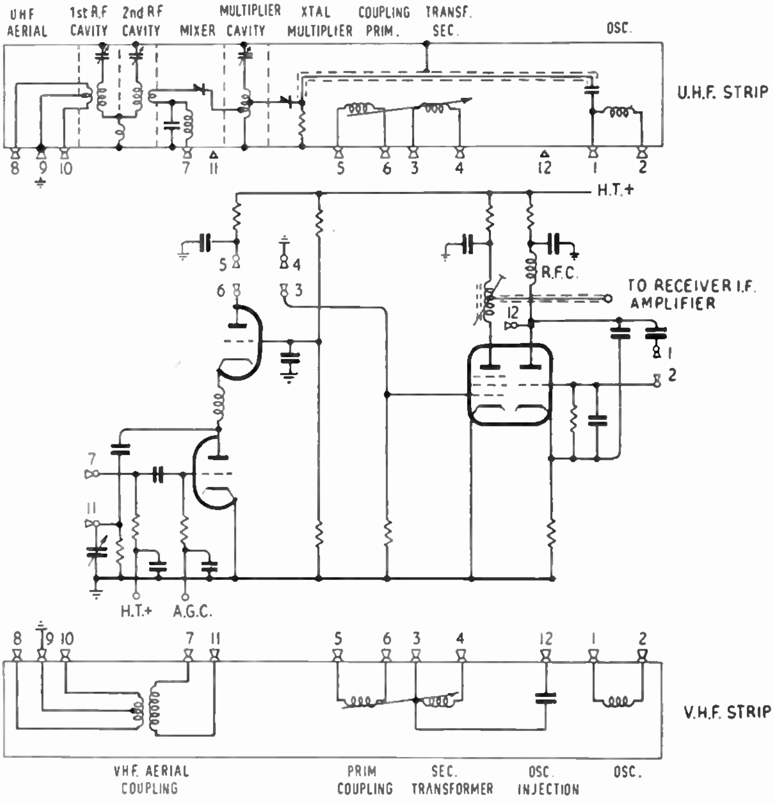


Fig. 19.—A v.h.f./u.h.f. head employing a rotary turret tuner.

capacitance of the amplifier stage. This method of matching is examined in Appendix 1.

From the circuit (Fig. 19) it will be noted that a bias is applied to the mixer crystal through contact (7) of the u.h.f. head, being connected to h.t. via a resistor. This bias maintains a constant direct current of about 0·5mA through the crystal and ensures that the crystal resistance, as seen by the i.f. input circuit, remains constant irrespective of oscillator voltage variations. This is required to be constant to maintain a correct match into the driven-grounded-grid amplifier for low noise. An interesting observation is that the crystal diode as a mixer produces noise, known as excess temperature noise, which is proportional to the amplitude of the oscillator voltage. First thoughts would be to keep the injected oscillator voltage small, but since the optimum conversion loss of a mixer of this type is about 9db, obviously any reduction in excitation, which would increase this figure further, could not generally be afforded. The claim made for the biasing method used in the circuit is that the crystal current is kept high so minimizing the conversion loss, whilst the injected oscillator voltage amplitude is small to minimize the excess temperature noise.

A model of a similar u.h.f. head, built in the authors' laboratory, utilizing lumped inductance/cavity capacitance is shown in Fig. 20. The head is built into a casting in which two cavities house the pre-selector coils and another the oscillator or multiplier coil. Coupling between the pre-selector coils is effected by the common inductance of a pin pressed into the casting to which one end of each coil is soldered. Capacitance between the free end of each coil and earth is varied by adjustment of the 8 B.A. screw entering the cavity from the bottom of the casting. This has a minimum capacitance of approximately 0·25pF and a tuning range greater than 100 Mc/s. The u.h.f. aerial is coupled into the first cavity, and the u.h.f. signal to the crystal mixer is taken off at the second cavity by loop coupling.

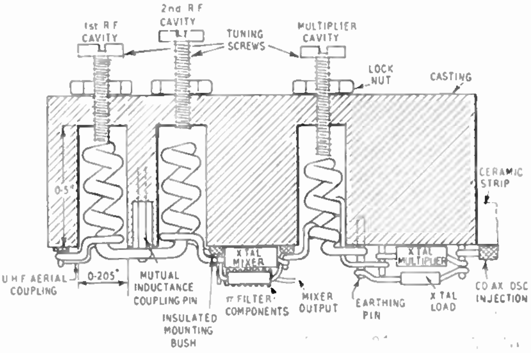


Fig. 20.—Prototype of a u.h.f. head contained in a machined brass block.

A later version of the head is shown in Fig. 21 in which the lumped constants are retained in a slightly modified circuit, and are carried on two ceramic strips for insertion in the rotary turret.

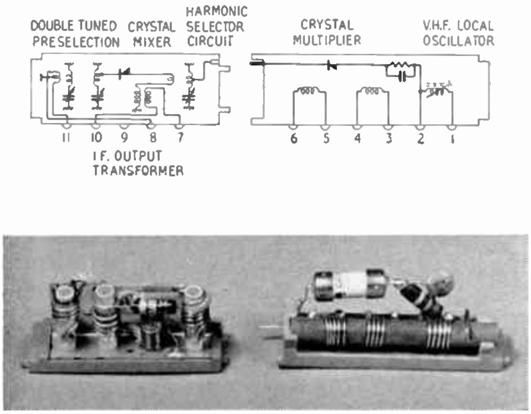


Fig. 21.—U.H.F. turret coil strips.

14. Eighty-two Channel V.H.F./U.H.F. Tuner

A v.h.f. rotary turret and the u.h.f. strip design of an American company have been embodied in a tuner to provide an eighty-two channel selection. The switched indexing method utilizes separate tens and units controls to obtain this channel selection, and is illustrated in the diagram of Fig. 22.

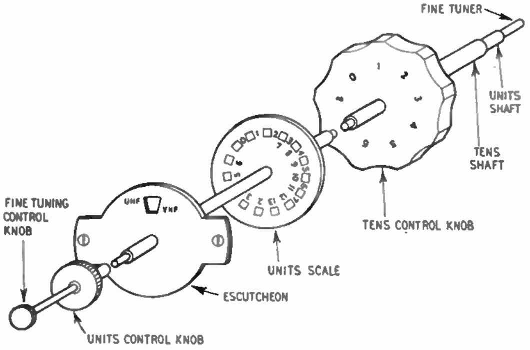


Fig. 22.—Tuning controls of an 82-channels turret tuning system.

An eight position u.h.f. tuner is rotated by the outer of three concentric spindles, with each position "broadbanded" to cover u.h.f. channels as shown in Table 8.

The output of the u.h.f. head falls within a frequency band of a v.h.f. channel. This output is switched through to a v.h.f. rotary turret. This provides for reception of the F.C.C. channels 2 to 13 by rotating the centre concentric shaft. A double superheterodyne system therefore operates on the u.h.f. channels.

In selecting a u.h.f. channel, the tens control knob is set to the appropriate tens number, this number becoming visible through the window of the units control knob. This operation selects the appropriate u.h.f. band. The units control knob is now set to the appropriate units number (selected from the outer circle of numbers on the units control knob) of the u.h.f. channel. This units number becomes visible on the right of the window. This operation rotates the v.h.f. turret to provide the correct first intermediate frequency channel for the output of the u.h.f. head.

Table 8

"Units" Control Channels
(U.H.F. Switched Channel Tuner)

U.H.F. Knob Position (tens control)	U.H.F. Channels
0	Switches v.h.f. aerial to v.h.f. turret
1	14 to 19
2	20 to 29
3	30 to 39
4	40 to 49
5	50 to 59
6	60 to 69
7	70 to 79
8	80 to 83

Table 9

"Units" Control Channels
(U.H.F. Switched Channel Tuner)

U.H.F. Unit Number (selected by v.h.f. knob)	1st I.F. Vision Carrier	Sound Carrier	F.C.C. Channel
0 ...	157·25	161·75	—
1 ...	163·25	167·75	—
2 ...	169·25	173·75	—
3 ...	175·25	179·75	7
4 ...	181·25	185·75	8
5 ...	187·25	191·75	9
6 ...	193·25	197·75	10
7 ...	199·25	203·75	11
8 ...	205·25	209·75	12
9 ...	211·25	215·75	13

Three additional positions are added to the v.h.f. turret, since the u.h.f. units 0, 1 and 2 do not fall within any of the F.C.C. v.h.f. channels 2 to 13. Thus, the units of the u.h.f. channels fall in the frequency bands as follows, which are the 1st i.f. of the system.

To select a v.h.f. channel, the tens (u.h.f.) control knob is set to zero. This switches the v.h.f. aerial through to the v.h.f. turret and disconnects the u.h.f. head. A shutter mechanism also operates to cover the u.h.f. units, leaving a v.h.f. channel number 2 to 13 visible through the window. The desired v.h.f. channel is then selected.

The i.f. output of the tuner of the eighty-two channels is at the recommended F.C.C. standard intermediate frequency.

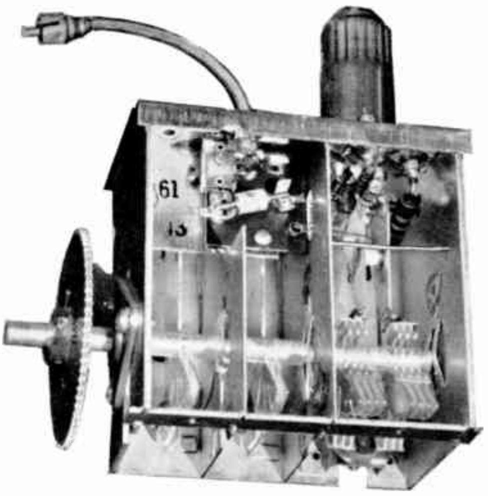


Fig. 23.—*A u.h.f. capacitive tuner.*

15. U.H.F. Capacitive Tuner

The tuner shown in Fig. 23 is a fine example of advanced development in which the elements of a four gang variable capacitor are built into the u.h.f. circuits in a very neat and simple manner. It is a continuously tuned unit covering channels 14 to 83 in less than 180 deg. rotation. The tuned circuits comprise end-tuned quarter wave lines, the ends of which form the stators of the variable capacitors. The vanes are shaped to give a linear tuning law. The circuit diagram in Fig. 24 shows that the two r.f. circuits are coupled by means of a slot in the screening partition to give a bandpass input to a crystal mixer. A 6AF4 valve is used as the oscillator in a Colpitts circuit with the oscillator frequency set above the radio frequency. Small metal strips bent up from the chassis close to the ends of the stators form the r.f. trimming capacitors, while two small variable capacitors enable low end and high end adjustment to be made to the oscillator. The whole tuner is well screened and occupies a space approximately 3½ in. × 2½ in. × 2¼ in.

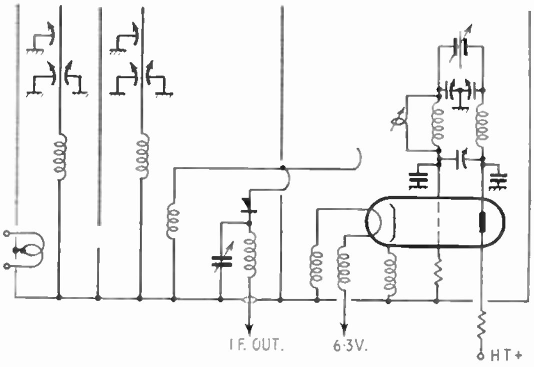


Fig. 24.—*Circuit of u.h.f. capacitive tuner.*

The short term stability of the oscillator observed by the authors under stable ambient conditions was excellent, being of the order of a few parts in 10^6.

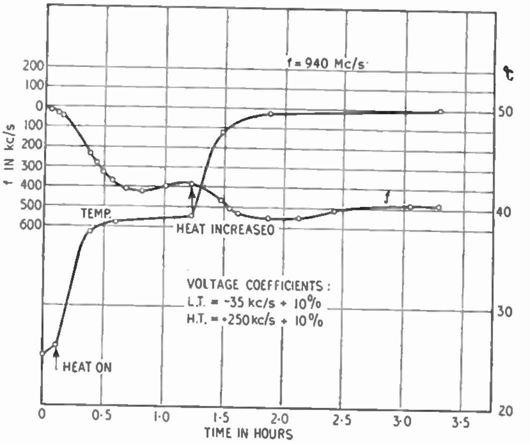


Fig. 25.—*Local oscillator drift of u.h.f. capacitive tuner at* 940 *Mc/s.*

A day's run with 6° C rise in ambient temperature showed a frequency drift at 540 Mc/s of only 15 kc/s. Fig. 25 shows a temperature run taken at 940 Mc/s.

At 540 Mc/s the frequency change for 30° C rise of temperature was about +100 kc/s. At 940 Mc/s the frequency change for a 25° C rise was approximately 600 kc/s.

The measured voltage coefficients were:—

540 Mc/s	HT	+ 30 kc/s per +10%
	LT	− 15 kc/s per +10%
940 Mc/s	HT	+250 kc/s per +10%
	LT	− 35 kc/s per +10%

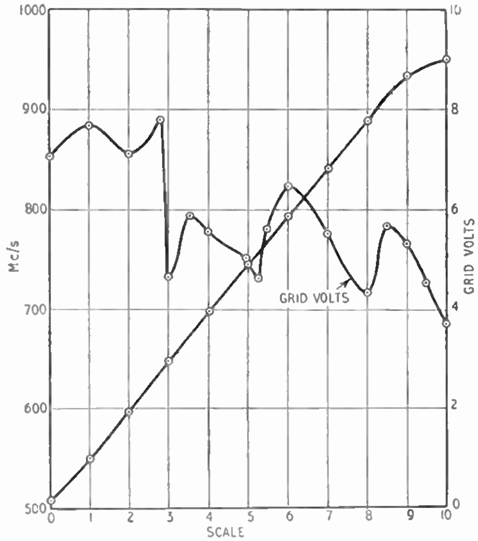


Fig. 26.—Local oscillator volts/frequency graph of u.h.f. capacitive tuner.

Figure 26 shows oscillator frequency plotted against a linear scale and variation of oscillator level over the range as indicated by the grid-bias developed. Other measured data are given in Table 10.

Table 10

Performance of U.H.F. Capacitive Tuner

Channel (F.C.C.)	Noise Factor db	Conversion Loss −db	R.F. Bandwidth (Mc/s)
500 Mc/s	10	7	10
850 Mc/s	20	16	15

16. Resonant Line Continuously Tuned U.H.F. Converter

A u.h.f. head using two tuned lines for pre-selection and local oscillator is a widely used system in the U.S.A. for u.h.f. converters, suitable for operation with a receiver incorporating a v.h.f. tuner. The general application of this type of head is for the output to be at a v.h.f. channel frequency which is applied to the v.h.f. tuner aerial terminals, so the system involves double conversion. The v.h.f. channel selected is one which avoids spurious responses in the double superheterodyne working, and of which no transmission is received in the area. For this purpose the u.h.f. converter output frequency is made adjustable from the rear of the unit.

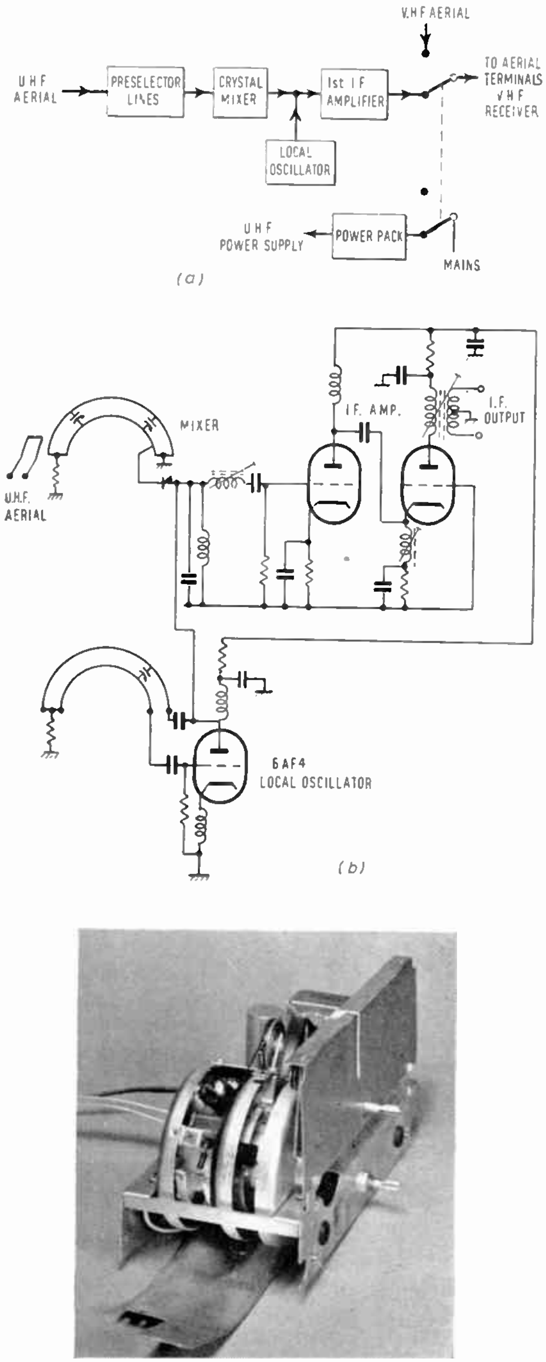
The pre-selector lines are half a wavelength long. The oscillator lines are a quarter of a wavelength long with the oscillator frequency lower than the u.h.f. signal frequency by the intermediate frequency. Both the pre-selector and oscillator lines are formed by ¼ in. wide silver plated strip, made circular to conserve space and to make the tuning drive mechanism simpler. The tuning mechanism with this type of head is an important consideration in the design, which must provide adequate screening and must be free of backlash. The sliders of the lines cover the u.h.f. range of 470 Mc/s to 890 Mc/s in 180 deg. rotation and are driven by a reduction cord drive from the front tuning control spindle. A 6 in. length scale travel is obtained between F.C.C. channels 14 and 83. Correct tracking is secured by adjustment of two variable capacitors on the pre-selector lines, one tuning the high end, the other the low end of the u.h.f. range.

As shown in Fig. 27 the output of the crystal mixer circuit is applied to a cascode first i.f. amplifier, tunable over channels (F.C.C.) 9, 10 and 11. The unit is self-contained with a power supply. Table 11 gives performance figures.

Table 11

Performance of Resonant Line Converter

Channel (F.C.C.)	Noise Factor db	Insertion Gain +db
500 Mc/s	16·5	5
800 Mc/s	22	2·1



(a)

(b)

(c)

Fig. 27.—A u.h.f. converter using tuned lines.

17. Rotary V.H.F./U.H.F. Turret Tuner

This tuner is designed for operation over the eighty-two channels allocated for television in the U.S.A. with the channel selected by the rotary coil turret principle. Single superheterodyne operation only is used both for v.h.f. and u.h.f. reception, with an intermediate frequency output of 45·75 Mc/s (vision) and 41·25 Mc/s (sound). The block diagram, Fig. 28a, shows this function where for v.h.f. a driven-grounded grid r.f. amplifier precedes a common silicon crystal mixer circuit with the local oscillator injection at the fundamental on both v.h.f. and u.h.f. The u.h.f. circuits preceding the mixer are without amplification.

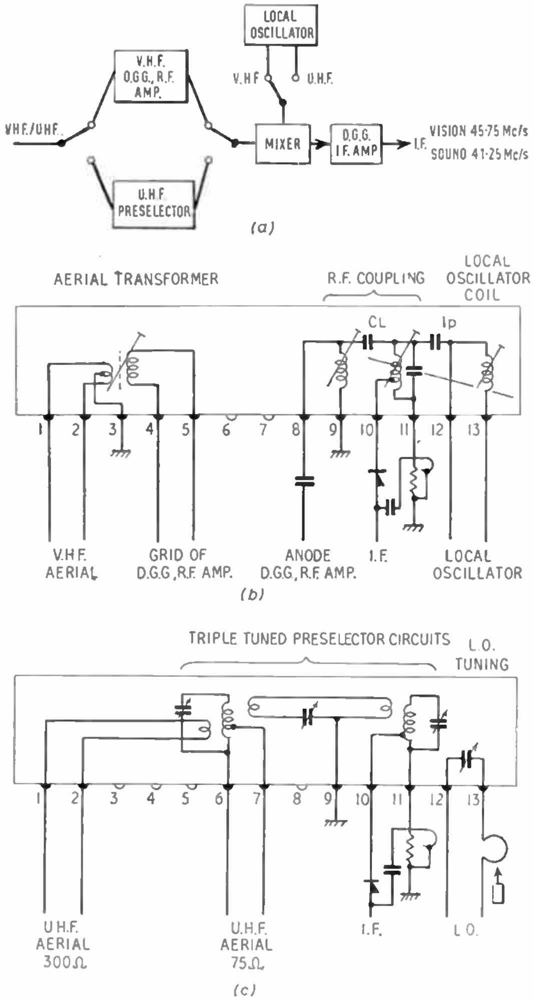
The circuit carried on a v.h.f. turret coil strip is shown in Fig. 28b. Bandpass coupling between the r.f. amplifier and mixer is achieved by top capacitance coupling with capacitor Cc. The oscillator coil is part of a triode Colpitts circuit with injection into the r.f. coupling secondary by capacitive coupling with the 1pF capacitor over channels 2–6 and mutual inductance coupling over channels 7–13. The oscillator fine tuning and injection loop shown are applicable to u.h.f. operation only, and although left in circuit perform no function on v.h.f. Twelve similar v.h.f. strips are carried on the rotary turret providing facilities for reception of the twelve v.h.f. channels.

The u.h.f. turret coil strips shown in Fig. 28c use lumped circuit constants with self-supporting tuning coils wound with silvered strip. The pre-selector circuits are triple tuned with an optional aerial input of 75 ohms or 300 ohms. Local oscillator injection is at the fundamental and is achieved by a coupling loop adjacent to the grid side of the triode circuit. The variable oscillator capacitance carried on the strip is series resonant with the small circuit

Table 12

Performance of Rotary V.H.F./U.H.F. Turret Tuner

Channel (F.C.C.)	Noise Factor db	Voltage Gain +db	I.F. Rejection −db Vision	Image Rejection −db Mid-band	R.F. Bandwidth (Mc/s)
4	4·5	77	79	59	
13	6·4	83	90	72	
19	13	10	90	46	9
83	16·4	5·3	90	50	8



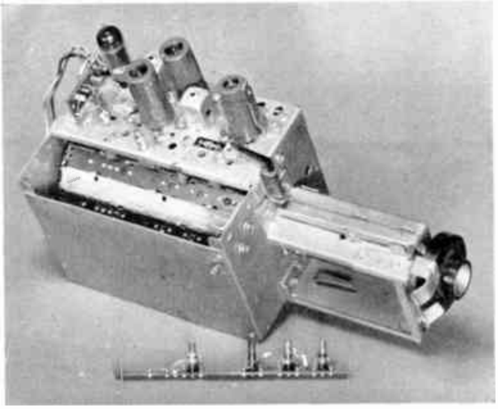

(d)

Fig. 28.—A v.h.f./u.h.f. rotary turret tuner.

inductance. The u.h.f. oscillator operates at the fundamental (i.e., from 517 Mc/s to 931 Mc/s over the channels 14 to 83) and voltage stabilization is provided for the oscillator h.t. supply.

The manufacturer's performance figures of the tuner are given in Table 12.

18. Acknowledgments

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21. Appendix 1: Pi Section Impedance Matching

In the cavity type u.h.f. head described, the pi section is designed as an impedance transformation device to match the crystal mixer resistance into the input resistance of the d.g.g. amplifier. The use of the section for this particular application apart from its conventional use as a low-pass filter section is examined with reference to Figs. 29a and b.

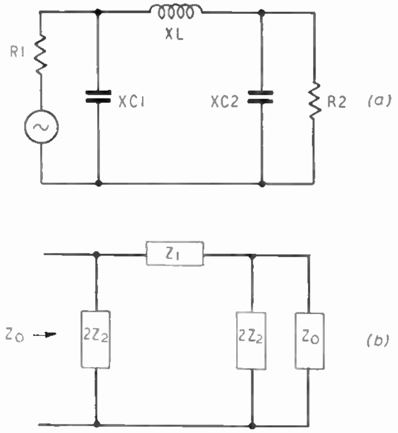


Fig. 29.—Pi matching section.

$$X_{c1} = \frac{-R_1 X_L}{R_1 \pm \sqrt{R_1 R_2 - X_L^2}} \quad \text{.........(8)}$$

$$X_{c2} = \frac{-R_2 X_L}{R_2 \pm \sqrt{R_1 R_2 - X_L^2}} \quad \text{.........(9)}$$

Equations (8) and (9) are derived from determination of image impedance by the open-circuited and short-circuited method. The condition then made in this approach is that the radical in both equations must be zero.

i.e. $X_L = \sqrt{R_1.R_2}$

Therefore $X_{c1} = -X_L$ and $X_{c2} = -X_L$.

Thus the circuit is a symmetrical pi section, from which:

$$Z_0 = \frac{Z_1.Z_2}{\sqrt{Z_1.Z_2 + \frac{Z_1^2}{4}}} \quad \text{...........(10)}$$

where $Z_1 = j\sqrt{R_1.R_2}$ and $Z_2 = \frac{-j\sqrt{R_1.R_2}}{2}$

$$Z_0 = \frac{\dfrac{R_1 . R_2}{2}}{\sqrt{\dfrac{R_1 . R_2}{2} - \dfrac{R_1 . R_2}{4}}} = \sqrt{R_1 . R_2} \quad ..(11)$$

Thus the characteristic impedance Z_0 is the geometric mean of the source and terminating resistances with matching conditions satisfied. The section is therefore a substitute for the $\lambda/4$ line.

22. Appendix 2: Impedance Measurement by Slotted Line at U.H.F.

The impedance of a point in a circuit which is required to be correctly matched, e.g., the crystal mixer into the pi filter of the u.h.f. head, may be determined by the slotted line technique[10,11] in which a movable probe is used to trace the standing wave pattern.

The line has a narrow milled slot along its length into which a probe penetrates to explore the radial electric field. The line impedance is known, and the signal generator source of the same impedance is connected at one end and the terminating impedance to be investigated is connected at the other.

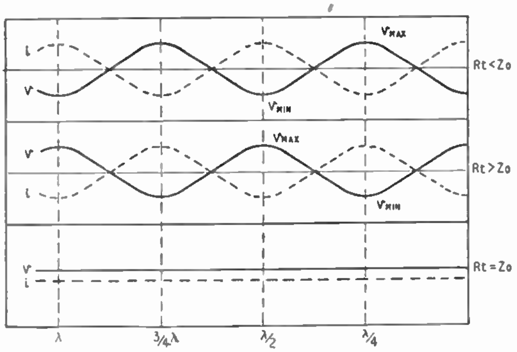


Fig. 30.—Standing wave patterns.

The standing wave patterns of resistive terminations are shown in Fig. 30. The probe is moved along to find the voltage maximum and minimum from which the standing wave ratio (s.w.r.) is found:

$$\text{s.w.r.} = \frac{V_{max.}}{V_{min.}} \quad \text{....................}(12)$$

The reflection coefficient (ratio of "reflected" to "incident" current), is then found from:

$$K_t = \frac{\text{s.w.r.} - 1}{\text{s.w.r.} + 1} \quad \text{.................}(13)$$

which is also given by:

$$K_t = \frac{Z_t - Z_0}{Z_t + Z_0} \quad \text{......................}(14)$$

where Z_0 = source and line impedance.
Z_t = terminating impedance.

$$Z_t = \frac{Z_0 \, (K_t + 1)}{(1 - K_t)} \quad \text{.............}(15)$$

i.e., with the line correctly matched, s.w.r. $= 1$, $K_t = 0$, $Z_t = Z_0$.

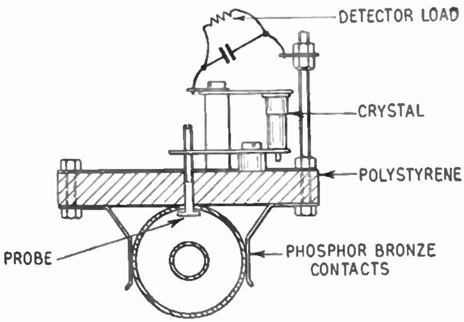


Fig. 31.—Movable probe for impedance measurement.

The drawing, Fig. 31, shows the movable carriage with the two phosphor-bronze contacts running along the outside of the outer conductor and a probe along the slot. A crystal detector completes the circuit. The depth of penetration of the probe into the line is adjusted by an 8-B.A. thread, and is made as small as possible, compatible with a working meter deflection, to avoid undue distortion of the field.

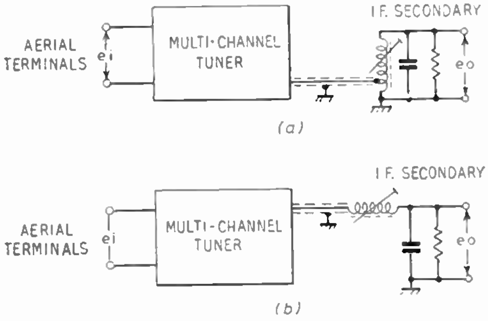


Fig. 32.—Method of gain measurement.

23. Appendix 3: Voltage Gain Measurement

Voltage gain measurements of the tuners described were made with one of the i.f. secondary circuits shown in Figs. 32a and b.

The voltage gain is given by:

$$\text{Gain (decibels)} = 20 \log \frac{e_o}{e_i} \qquad \ldots\ldots\ldots\ldots\ldots(16)$$

24. Appendix 4: Cosmic Noise Level as the Deciding Factor of Permissible Receiver Noise

The aerial noise temperature graph by Moxon[12] (Fig. 33) shows the variation of cosmic noise level with frequency, for 350 degrees galactic longitude, to be of the form

$$T_a \propto \frac{1}{f^{2.7}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(17)$$

The cosmic noise power input to the television receiver is given by

$$P_{cn} = KT\Delta f \qquad \ldots\ldots\ldots\ldots\ldots\ldots(18)$$

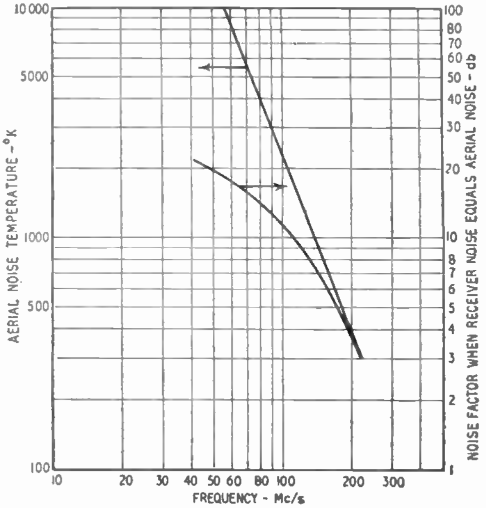
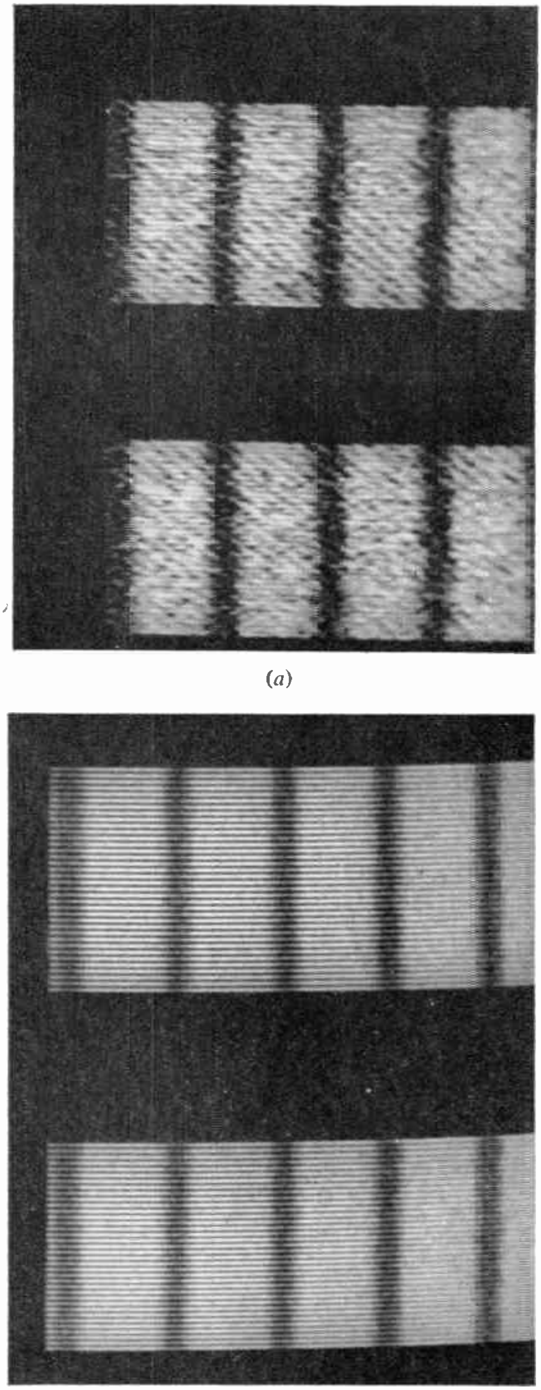


Fig. 33 (above).—Variation of cosmic noise level with frequency and permissible noise factor.

Fig. 34 (right)—(a) Broken line structure produced by tuner using grounded cathode pentode; (b) Broken line structure produced by tuner using driven-grounded-grid radio frequency amplifier.


(*a*)

(*b*)

where K = Boltzmann constant $1{\cdot}37 \times 10^{-23}$ joules per degree Kelvin

T_a = aerial noise temperature in degrees Kelvin

Δf = bandwidth $3{\cdot}5 \times 10^{6}$ cycles for the British system.

Table 14

Cosmic Noise Aerial Power

Frequency (Mc/s)	Aerial Noise (Watts)
56	$4{\cdot}8 \times 10^{-13}$
73	$2{\cdot}4 \times 10^{-13}$
100	1×10^{-13}
135	$4{\cdot}8 \times 10^{-14}$
220	$1{\cdot}4 \times 10^{-14}$

The ideal receiver would generate $K.T_r.\Delta f$ input power only. Let $T_r = 290°\mathrm{K}$ (room temperature)

$$P_{rn} = 4 \times 10^{-21} \times 3{\cdot}5 \times 10^{6} \quad \ldots\ldots\ldots\ldots(19)$$
$$= 1{\cdot}4 \times 10^{-14}$$

If the receiver generates no other noise, it will have the best possible noise factor i.e., 3 db (under matched conditions). The required noise factor for the receiver noise to equal aerial noise is given by:

Required noise factor

$$= 10 \log \frac{\text{aerial noise power}}{\text{noise of ideal receiver}} + 3 \ldots\ldots\ldots(20)$$

$$= 10 \log \frac{T_a}{T_r} + 3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(21)$$

Eqn. (21) is plotted in Fig. 33 from which it is seen that the required noise factor above 100 Mc/s should progressively decrease from 11db to 3 db at 220 Mc/s; below 100 Mc/s the noise factor may increase to 22·2 db at 40 Mc/s.

In endeavouring to achieve these results, the merits obtained by using the driven-grounded-grid circuit, are brought out in the photographs of Fig. 34. This allows a comparison of two similar type receivers in which one uses a d.g.g. and the other a grounded cathode r.f. amplifier. A low level closed circuit signal is applied to each, with receiver sensitivity at maximum.

The order of noise level difference shown in the photographs is similar to that obtained during field tests in fringe areas. It is in such areas that the question of signal/noise ratio and the importance of first stage design becomes most evident.

Golden Jubilee of the Royal Aircraft Establishment

This year was the 50th anniversary of the setting up at Farnborough of the Government research and development station now known as the Royal Aircraft Establishment. Originally associated with the Royal Engineers, it was known in 1905 as H.M. Balloon Factory; the present name dates from 1918, when the Royal Air Force was formed.

The Golden Jubilee was marked by an Open Day on July 7th, when H.R.H. Princess Margaret visited the Establishment. An extensive and comprehensive exhibition and flying display relating to the part played by R.A.E. in the development of aviation were held to which representatives of science and engineering were invited, including the President, Immediate Past President, and General Secretary of the Institution. On the following day a more general invitation was issued to industry and research.

In elaborating on the theme of 50 years progress in aviation, the Exhibition consisted of two sections: the historical development and the work of R.A.E. today. As an example of the original work at Farnborough a number of balloons were shown in actual and model form as well as man-lifting kites. Historical aircraft displayed included a number from the 1905 to 1918 period, several of which were developed and actually built at Farnborough.

During the flying display some of these original aircraft were flown and provided an interesting contrast to the high-speed turbo-jet propelled aircraft of today. A number of aircraft of the intermediate period, both before the last War of the 20's and 30's and of World War II also took part in the display.

In parallel with its work on aircraft the Royal Aircraft Establishment has been concerned with the development of allied techniques of associated equipment, including radio and communication of aircraft ground and air equipment, showing progress from the earliest days up to the latest miniaturized multi-channel u.h.f. transmitter receivers. Points worthy of note in this display included the first superheterodyne receiver to be used in aircraft around 1925 and an airborne transmitter receiver developed in 1936 which continued in operational use throughout the whole of the last war. Component development over the period has shown some striking advances, mainly, of course, in the increased efficiency with ever decreasing size, and all radio engineers will be familiar also with the new techniques now available using "potted" and "printed" circuits. Microphone and telephone development has been guided by the particular problems which have to be overcome due to the high noise levels experienced in modern aircraft and here again miniaturization has played its part in providing lightweight apparatus.

Broadly speaking the work at R.A.E. in the field of radio and electronic engineering falls into the groups of radio communication, certain navigational aids concerned with the guidance of self-propelled missiles, and instrumentation techniques (Research and development on radar and pulse navigation systems are, of course, principally carried out at the Radar Research Establishment, Malvern).

Aerial research is especially important since installations in aircraft are profoundly affected by the shape of the aircraft as a whole. Consequently, special techniques have to be devised and a demonstration was given of the polar diagrams of radiation obtained from various aerial positions on a typical aircraft. The Radio Department is developing a sono-buoy which is dropped on a parachute by a submarine-hunting aircraft. This picks up the underwater noise made by a submarine and relays it by radio to the aircraft. By dropping a number of buoys the exact location of the submarine can be found. Techniques allied to radar are employed at R.A.E. in the control of pilotless target aircraft and in the pulse type of radio altimeter. In the former a small aircraft has been developed which can fly at 200 knots and climb to 16,000 feet. It is fitted with a control system developed at R.A.E. which works in conjunction with an auto-pilot. Should it escape from radio control for any reason, its power is automatically switched off and a parachute released to control its descent to the ground or sea.

The development of flight landing systems has now reached a high degree of efficiency and the latest types of automatic control approach aid takes over the control of the aircraft from the auto-pilot, thus leaving the pilot free to monitor instruments and look out for the approach lighting beam preparatory for taking over for a manual landing. The exhibits at the Exhibition included a model airfield showing the disposition of radio, radar and visual approach aids, and a flight similator coupled to an autopilot which is used to demonstrate the improvement obtained by various approach aids.

Guided weapon development makes use of many techniques in aircraft and electronic engineering and a general display was given of some of the aspects involved. Three types of guided weapon were featured: namely the Command-link, the Beam-riding, and the Homing types; the techniques used in their control call for precision radar measurements and the telemetering of parameters to the controller. An important aspect of the work of the Guided Weapons Department is the development and use of simulators for forecasting the effect of changes in flight conditions. Simulators of the analogue computer type can eliminate the need for a large number of expensive trials involving complete missile firings. In addition to simulators of a fairly limited application, the equipment of the Department includes what is the most advanced equipment in this country for simulating flight control, namely the analogue computer TRIDAC (three dimensional analogue computer). The physical statistics of this computer are most impressive: it occupies 6,000 square feet of floor space (a complete building houses it), 8,000 valves are used, up to 650 kW are taken from the supply mains.

The basic analogue quantity in the computer is a d.c. voltage and the basic element in the majority of the computing units is a high-gain d.c. amplifier with input and feed-back impedances arranged to give an overall transfer function corresponding, for example, to addition or integration; there are approximately 600 d.c. amplifiers which are associated with a similar number of stabilizers of the "mechanical chopper" or magnetic modulator type which confine the drift of the d.c. amplifiers to within a few millivolts. Multiplication in the computer is carried out by arrays of potentiometers driven by electrically controlled hydraulic servometers. A particularly valuable feature of the computer is that it works in the same time scale as the "real" system and hence actual components from the aircraft under investigation can be included in its operation.

Telemetering has already been referred to and a demonstration was given of the use which can be made of these techniques. An aircraft carried out a number of manoeuvres over the Establishment and parameters such as the aileron and rudder movement, "g," and altitude were transmitted by suitable transducers to a multi-channel equipment connected to easily visible meters.

Since the emphasis of the investigation work of the Establishment is necessarily on accurate measurement, the function of the Instrumentation Department in designing and constructing special instruments is of increasing importance. Many observations are obtained in the form of continuous-trace recording and apparatus has been devised for increasing the speed and accuracy of reading and analysing such records. This consists of a movable cursor, set to any desired point on a trace, and releasing pulses which depend on its position; the pulses are passed through conversion circuits which apply appropriate scale factors and then print out the results on an electric typewriter, tabulated, correct to three figures, and expressed in the required units of measurement, such as pounds per square inch or miles per hour.

Mechanical transducers of a variety of types for measurement of vibration, acceleration and pressure, and the associated calibration techniques were demonstrated. Miniature and subminiature multichannel amplifiers for use in conjunction with transmitters have been developed. Interesting techniques making use of magnetic recording of the transducer signals are also employed and other methods of recording flight test measurement include the use of punched tape which is then fed into an electric typewriter, and high-speed camera recording of oscillograph tracers.

The Flying Display at the Open Day was an interesting comparison with the well-known display which has been held annually at Farnborough in recent years by the Society of British Aircraft Constructors. While including spectacular performances by high speed modern aircraft it also featured displays which are more in the nature of an "Air Pageant." The close formation flying by fighter and heavy bomber aircraft, and by helicopters, was most impressive and was a striking demonstration of the value of v.h.f. air-to-air radio communication in modern aerial manoeuvres.

V.H.F. BROADCASTING USING FREQUENCY MODULATION*

A Discussion Meeting in London on April 13th, 1955

In the Chair: Mr. Paul Adorian (a Past-President)

The B.B.C.'s Plans†—K. R. Sturley, PH.D., B.SC.‡

About four years ago a paper was published in the *Journal* in which the author strongly advocated the use of amplitude modulation for v.h.f. broadcasting, and in the discussion and subsequently,[2] your then President commented that whilst a.m. appeared to have short-term attractions, frequency modulation appeared to offer the better service. The a.m./f.m. tests from Wrotham reported in the *B.B.C. Quarterly*[3] showed quite clearly that f.m. was technically superior. Controversy has raged fast and furious on the relative merits of the two systems of modulation) but the issue was finally settled through the acceptance by the Government of the report of the Television Advisory Committee[4] which pronounced strongly in favour of frequency modulation.

Present day reception conditions have brought home to most people the limitations of long and medium wave broadcasting but, even apart from the present wavelength chaos, it is probable that attention would have been directed to v.h.f. broadcasting because of two things: our experience of the good quality that can be obtained with the sound accompanying a television programme, and the improved valve and circuit techniques which have made the commercial exploitation of v.h.f. by domestic receiver manufacturers possible. The freedom of v.h.f. propagation from ionospheric reflection except under freak conditions reduces the possibility of adjacent channel or common wave working interference from stations geographically far apart, and there is nothing equivalent to the "after dark" interference experienced on medium waves. Unfortunately v.h.f. propagation is much more variable in field strength than long and medium wave propagation, and shadow effects from hills and objects large compared with the transmitted wavelength can cause serious reductions in local field strength when the average surrounding field strength is adequate. It is under these and fringe area conditions on v.h.f. that f.m. demonstrates its superiority over a.m. for it provides a far better signal-to-noise performance than does the comparable a.m. system.

The discussion to-night is a twofold one, and my task is to indicate the special problems which those responsible for transmission have to face. Some idea of the magnitude of the task is seen by quoting from the White Paper already referred to. If the three sound programmes are to be available to 97 per cent. of the population, it is estimated that 75 transmitter units having a total aerial input of about 760 kW will be required. Capital outlay for buildings and plant would be about £3,000,000 and the annual cost £800,000. At the present time the B.B.C. is embarked upon the building of the ten stations that have so far been approved by the Government. Each will radiate the Light, Home and Third programmes. These 10 three-transmitter stations will serve about 83 per cent. of the population. (See Fig. 1.) The further stations that are planned, which will increase the coverage to 98 per cent. of the population, have yet to be approved by the Government.

Let us start at the programme source and trace the technical problems which may be introduced or accentuated by the use of f.m. The greatly improved sound quality possible from v.h.f. reception will probably make the listener more conscious of studio and apparatus deficiencies. Though studio design has a large element of trial and error, continuing research is revealing the conditions for satisfactory performance and how to correct boom, jangle, etc. Even with improved studios, the positioning of the microphone will continue to be very important since the ratio of direct to indirect sound determines the impression of depth and size of the sound source such as an orchestra. There is nowadays no essential difficulty in producing a high quality microphone, whose performance as a transducer is quite satisfactory, and whose

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U.D.C. No. 621.396.97.029.62:621.376.3.

Fig. 1.—This map illustrates the coverage to be expected from the ten stations to be erected in Stage I of the V.H.F. Plan. The station at Penmon is a temporary expedient to broadcast the Welsh Home Service pending the erection of a three-transmitter station in Stage II of the Plan.

(*By courtesy of B.B.C. Publications*)

size is small enough to cause little distortion of the sound field. Though the dynamic range of the programme transmitted by frequency modulation could be increased beyond the present 25 db, it is by no means certain that this is artistically desirable. As far as can be seen control of programme volume range will need to be exercised and limiters included in the programme chain to prevent harmonic and intermodulation distortion in the receiver due to excessive frequency deviation.

No technical problems, which have not already been surmounted, are likely to be met in the amplifying apparatus. The lines linking studio centres and their local transmitters are, in general, capable of accepting the increased audio frequency range made possible by v.h.f. broadcasting. The music lines for interconnecting studio centres up and down the country have at present an upper frequency limit of 8 kc/s, and many will be satisfied with this quality after their experience of the much narrower band medium wave reception. The critical listener in, for example, London, will note the difference in quality between a programme originating in London and one from Edinburgh. Time will doubtless resolve this problem for there are no technical difficulties in expanding the frequency range, although economics cannot be ignored.

High quality disk and tape recording equipment is already in use so that recorded programmes could now fully exploit the capabilities of f.m.

The transmitting apparatus will tend to be a little more complicated in operation than the medium wave transmitter and the same is true of the three programme combiner network feeding the wideband slot aerial. Since no power will be required from the modulator there will be no difficulty in providing the required modulation up to the highest audio frequency. Greater skill may be required of the operator in aligning the r.f. circuits of the transmitter.

It will be seen that the use of frequency-modulated v.h.f. broadcasting brings for the broadcasting engineer and operator few problems which he has not already encountered and overcome. Some changes in technique will be called for but all can be acquired or imparted by a suitable training programme.

The listener will find foreign station interference negligible and impulse interference (ignition noise, etc.) much reduced if not eliminated. Where foreign station interference is not serious on medium wave reception, existing receivers will still continue to be useful, for the B.B.C. has no intention of closing down medium wave transmitters.

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Some Industrial Problems*—F. T. Lett (*Associate Member*)†

I would like to congratulate the Government on their decision to permit the B.B.C. to embark on this chain of v.h.f./f.m. transmitters to provide a public service. The Germans and Americans have already had several years' experience in this field, but the B.B.C. have been prevented by national economic considerations from starting a public service until now.

As a receiver manufacturer, I am very worried by a recent statement made by the B.B.C., which indicates that they do not intend to take full advantage of the high fidelity offered by this technique, as their existing landline equipment limits them to 8 kc/s response. Why cannot the B.B.C. use equalizers to avoid this limitation on existing v.h.f. links?

The incorporation of the f.m. band into an average table model receiver involves an increase in the list price, including purchase tax, of at least £4. Assuming that, at the present time, approximately 80 per cent of the listening

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public get adequate service (up to 5 kc/s response) from their medium wave receivers, how can we justify this increase in the cost unless it can be demonstrated that there is a worth-while improvement in quality from the new service?

I understand that the Germans are using up to 15 kc/s and, in some cases, even 20 kc/s for their best orchestral transmissions. From personal experience gained while listening to some of their better class receivers, the results are excellent and would more than justify this extra cost to any listener who is really interested in music and who, today, is prevented from getting it from his receiver because of the limitations of medium waveband. Nothing could be more disastrous economically than to call on industry to produce a duplicate range of receivers, one for a.m. and the other for a.m./f.m.

I also welcome this new service because a.m./f.m. sets are popular in the European market, and a large home demand will enable us to compete more successfully in the export trade.

We have recently made some tests which indicate that Wrotham has a better service area than the London Regional medium wave transmitter and it would be interesting to know whether other members agree with this view?

Domestic F.M. Receiver Design Considerations

Aerials.—A simple dipole aerial tuned to the middle of the band either in the form of an indoor aerial or housed in a console cabinet appears to give quite satisfactory results in most areas. A 70-ohms balanced line would seem to provide the best compromise for aerial-to-set feeder.

F.M. convertors.—Convertors to connect to the low frequency input of existing a.m. sets, although attractive at first sight, have the disadvantage that their costs are comparatively high and their performance usually very disappointing. The cost is high because they involve at least 4 valves, a power supply and cabinet, while performance is very disappointing, because although their circuitry allows a better frequency characteristic, the overall performance is limited by the l.f. amplifier characteristic and loudspeaker equipment of existing a.m. receivers. History in Germany shows that sales were poor and most convertors were withdrawn from the market after the first year of f.m. transmission.

A Domestic A.M./F.M. Receiver Design

R.F. stage for f.m.—To avoid oscillator radiation from the aerial and to provide a reasonable level of signal at the frequency changer, a r.f. amplifier appears essential. This can conveniently be a grounded grid high slope triode to give low noise at this frequency and a stage gain of 10/1.

Frequency changer for f.m.—A self oscillating triode frequency changer is a very satisfactory arrangement and this valve can be contained in the same envelope as the r.f. valve if suitably screened. This leaves the a.m. frequency changer free to operate as first i.f. amplifier on f.m. and provides the easiest switching arrangement between a.m. and f.m.

It is advisable to operate the oscillator at a higher frequency than the incoming signal to avoid image reception from the top of Band I (T.V.) although this may be more likely to interfere with Band III (T.V.) if oscillator radiation from the aerial is not fully suppressed. A conversion gain of 40/1 can be obtained with this arrangement.

I.F. amplifier for f.m.—The usual 10·7 Mc/s intermediate frequency, as used in Germany and the U.S.A., has been adopted for f.m. and 470 kc/s for a.m., a switch bringing in alternative i.f. transformers.

The first i.f. amplifier on f.m. is the heptode of the a.m. frequency changer valve, and the second a pentode with a slope of 6mA/V. Both stages require neutralising to achieve stability and to avoid feedback producing phase distortion and distortion of the bandpass curve.

Detector for f.m.—The author favours the use of a ratio detector as an addition to providing detection, this also provides sufficient limiting action to make a further i.f. limiter stage unnecessary. A triple diode triode valve provides suitably balanced low resistance diodes plus a third diode for a.m. detection, the triode being used as i.f. amplifier on a.m. and f.m.

Germanium diodes seem to be a doubtful choice unless these are specially selected in pairs of equal resistance.

Tuning indicators for f.m.—The author has not found it necessary to provide visual tuning indication for the average person to tune a set correctly during trials, but the necessity or otherwise of this feature is very much a matter of individual opinion.

Wavechange switch.—The German "Piano Key" type switch lends itself extremely well to provide switching of r.f., i.f. and l.f. sections of the set necessary in a.m./f.m. receivers, and to provide a front control. Alternatively, the conventional rotary switch can be used with the spindle parallel to the front of the chassis providing side controls are acceptable on the receiver.

L.F. amplifier.—It is necessary to design an l.f. amplifier with a very low harmonic content, as distortion is far more objectionable when a wide frequency band is being employed. For this reason it is also advisable to use a larger output valve than for a.m. and operate it more conservatively.

In high quantity equipment the l.f. pass band should be much greater than the frequency band received to avoid ringing and similar sources of distortion.

Loudspeakers.—Loudspeakers of fairly conventional design can be obtained to give a flat response up to 8 kc/s. Above this it is usual to employ a specially lightened speech coil and possibly a metal or a metal and paper cone, such speakers reach 12-13 kc/s. For higher frequencies it is necessary to use an additional high frequency loudspeaker which can be of the electrostatic type. This combination can provide a flat response up to 20 kc/s.

The Battery A.M./F.M. Receiver

In this field we find ourselves in great difficulty. The design of a high fidelity battery receiver with reasonable sensitivity and freedom from oscillator radiation would involve approximately nine valves and this would necessitate a very high cost per hour in battery consumption.

German designs investigated appear to accept a normal a.m. fidelity and internal aerials to avoid oscillator radiation. No r.f. stage is used but by use of a bridge circuit the self-oscillating triode f.m. mixer is prevented from producing too much oscillator radiation provided internal aerials are used of low radiating efficiency.

Again the a.m. mixer is used for the first i.f. amplifier on f.m., followed by two additional i.f. amplifiers, germanium detectors, and l.f. stage followed by a single or push-pull output stage. Such a set can be reduced to six valves thus having a 50 per cent. increase in operating costs per hour when compared with a similar a.m. battery receiver.

DISCUSSION

The Chairman: Dr. Sturley mentioned the difficulty of getting good frequency response on the existing G.P.O. lines, and said that to get twice the response may mean more than twice the cost. I wonder whether the very old scheme whereby the upper octaves are reconverted to ordinary lower frequencies could be used. If we are to transmit 12 kc/s everything above six is converted to below 6 kc/s and sent out on one line. Except for the terminal equipment—which is not very expensive—the cost becomes double because two lines are employed. The scheme has been employed for sending fairly high quality broadcast programmes on low quality lines. This should work out cheaper than micro-wave links.

Another point that was mentioned by Dr. Sturley was that we only have one ear with conventional broadcasting methods. As apparently the B.B.C. is going to continue with the medium wave transmission, it might be interesting if in fact the medium wave transmission were used for the left ear and the new transmission for the right ear. Those who really wanted high quality could, at the cost of extra equipment, introduce that refinement to their home equipment.

C. L. Burnard: There are two distinct techniques in communications at v.h.f. and broadcasting at v.h.f. In the former the oscillator stability problem is overcome by quartz crystals and use of band pass filters, either by direct control or by some form of economiser device. In some specialized f.m. communication applications the deviation is narrow and there is a restricted frequency response. There is, of course, a very different specification for broadcasting including much wider deviation and therefore a very much wider audio frequency bandwidth. We have however to achieve these refinements at a reasonable price, and generally have to incorporate a m.f. a.m. receiver as well.

Nearly all m.f. a.m. receivers are quite easy to handle since they can be tuned in a simple manner with the gain being looked after as from station to station. However, as Dr. Sturley mentioned, you can get quite large signal variations on v.h.f. from point to point in different parts of even a small district and it is necessary to build a receiver that has quite a high gain, higher than anything we would normally employ for an equivalent m.f. set.

I have come up against the problem that if one does not have a tuning indicator, and the effective limiting in the set and the automatic gain control are good, it is difficult to tune the set unless the modulation of the wanted station is high, that is to say, the range over which you may tune the set is narrow for a low distortion.

A further point is that the ratio detector will largely reject ignition interference and spurious transmission but it will only do so satisfactorily if designed so that the rejection position lines up with the point at which distortion is also low. Otherwise, you may tune the set to a point where the ignition interference has largely vanished, but where the signal is not as pure as it might be.

With this technique, giving us without interference a wide bandwidth at low distortion, we need good quality components; for instance output transformers if wound in a simple manner, may have quite a large leakage reactance which limits the frequency response or distorts it. It is necessary also to have a speaker which covers a wider frequency range. Quality of design and workmanship must be high to reduce noise in switches, etc. Whereas in m.f. transmissions (particularly under modern conditions) there is nearly always some form of interference present, anything of this nature will make itself felt much more in f.m. reception where there is a completely quiet background.

On the other hand, by taking great care in the layout and circuit design we can achieve all these things and keep the cost down. Largely this is done by combining things like the i.f. amplifier in such a way that valves perform more than one purpose; that has to be done very carefully to use the minimum of switching. It has been suggested that the i.f. amplifier should be switched completely but that can produce other unfortunate results, particularly if using a switch of a normal commercial type which is not absolutely quiet.

You need to have good tone control and filter circuits; this may sound strange but it appears to me that some of the speakers on transmissions from Wrotham either have not completely mastered the microphone technique or their voices are, perhaps, whilst acceptable on m.f. a.m. transmitters, not so completely acceptable when it comes to f.m., for where a small amount of splutter otherwise would hardly be noticeable, chest tones or anything excessive on f.m. can be noticed immediately and can be quite distressing.

In all this we are using r.f. techniques which are not so fully proved as the techniques used on the medium frequencies. We have to use triodes for amplification and for mixing at the moment, so we have to avoid radiating at oscillator frequency. We need elaborate circuits to avoid interfering with other services. Similarly, we do not want other services to interfere with us and for that reason the industry has largely standardized on 10·7 Mc/s for the i.f. with the oscillator on the high frequency side of the signal carrier.

With regard to future developments, it would appear that we may be helped by the use of germanium diodes. They look fairly promising, although they are quite critical in operation as regards temperature; care has to be taken here. Then it would be useful if we could have a separate i.f. amplifier to avoid switching, because it seems a.m./f.m. sets will be with us for some time to come. The f.m.-only set is probably little more than a dream at the moment.

J. R. Brinkley (*Member*): I should like to know where Mr. Lett hopes to find the export market he refers to, as we know very well from studying the situation in many countries which have had f.m. broadcasting for a long time, that we cannot export receivers to these countries. We have examined the African market to see whether f.m. is the answer to better reception in the tropics, but unfortunately technical difficulties seem to be against the f.m. receiver. As Mr. Lett points out, it is very difficult to make a battery-operated receiver. It is not economic in this country; and quite impossible for the African continent.

Dr. Sturley said that there are no problems which have not been overcome on the transmitter side. There is one problem—a very important problem—which I think has still to be mastered. In the Wrotham transmitter, the B.B.C. has engineered an ingenious system using one common aerial with three transmitters. The spacing between each of these transmitters is about 2·2 Mc/s, roughly 2 per cent. of carrier frequency, and the separation of each transmission from the other has involved the use of very closely spaced filter circuits giving about 60 db rejection between individual carriers. This is sufficient from the point of view of making sure one transmitter does not blow the other up, but from the point of view of spurious radiation it is very much open to question. Calculations of the amount of mixing that will take place between transmitters show that the spurious radiation can be expected at a level of about −60 db. That may sound very little insofar as it concerns transmitters on much lower frequencies, but in the case of Wrotham it is a very high level of interference.

Our Company has been conducting an investigation of intermodulation between transmitters, the effects of which we have found to be very important and we shall be interested to see how the B.B.C. has solved this problem. The intermodulation products have been calculated and measured.

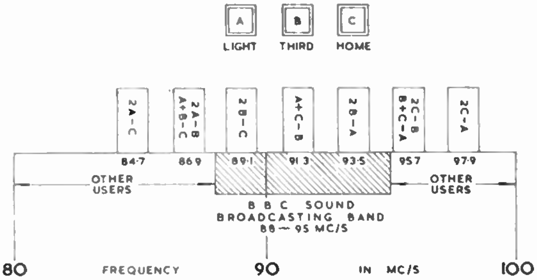

Fig. 2.—3rd order intermodulation products at Wrotham.

In Fig. 2 the base line shows the frequency band 80–100 Mc/s, while the 3rd order intermodulation products relative to the three Wrotham carriers are shown above the affected frequencies. Not all of these products have been measured but a number have been checked and found to be about 70 db down. 5th order products increase the number of spurious radiations still further with some 3rd and 5th order products coinciding.

The interference caused by the spurious radiations assume various interesting forms. With one form, ($2A - B$), which carries the modulation of one carrier at twice deviation, two sets of modulation are received. The combination of the Light and Third Programmes will produce some rather curious results!

The level of −70 db corresponds to a 5-microvolt signal at a considerable distance and this level has been measured at distances up to about thirty miles. We have drawn the B.B.C.'s attention to this fact and it is hoped that they will be able to reduce the levels considerably.

It is not only the B.B.C. Wrotham transmitters which offend in this manner. All transmitters tend to exhibit the fault and it shows the complete inadequacy of the Atlantic City levels of suppression as applied to high power transmitters. Levels of spurious radiation are generally −40 or −60 db and have been adequate for most a.m. transmitters on the lower frequencies. The levels are, however, quite inadequate for v.h.f. broadcast transmitters and if they continue to radiate the spurious emissions, serious interference will be caused to other services.

J. H. Holmes: My concern is with the lines which link the transmitters with the studio centres, and I should like to make just one or two points in that connection. First of all, there is the question of the frequency bandwidth which could easily become a bone of contention. On the one hand Dr. Sturley thinks that many people will be satisfied with an upper audio-frequency limit of 8 kc/s; on the other hand, Mr. Lett thinks a great many people will not be satisfied at all; and in the middle we have the Chairman's admirable suggestion of a split-band system which, I might say in passing, is fairly extensively used in the B.B.C. in another connection, namely, for collecting outside broadcasts from places where it is impossible to get a line of good music quality. This suggestion would certainly lead to a doubling of the cost of the line network because you would in fact need two lines of music quality, for which there is a standard tariff rate applied by the P.O. In addition to that, there would be the special equipment which would be necessary to enable the band splitting to take place.

Although Dr. Sturley's point may well be true, there does seem to be a very widespread conviction that the main merit of the f.m. system of transmission is the greatly increased audio-frequency band-width which can be transmitted.

Secondly, it is undeniable that there is a very widespread interest in high quality reproduction of sound and it can be taken that the first listeners will be the keen ones who may feel disappointed that the full frequency band-width is not available to them. The B.B.C. does not intend to radiate 15 kc/s from all transmitters, because of the limitations imposed by Post Office lines. It is not that the G.P.O. could not produce lines which are capable of transmitting the frequency band-width, but because we have not asked them to do so, nor do we intend to. The reason for that is the economic one which has already been mentioned: the cost of a line to transmit any given frequency band is very closely related to the band of frequencies it is required to transmit, and after careful consideration we do not feel the extra expense would be justified at present.

However, I think Dr. Sturley is a little bit pessimistic about the frequency band-width we shall achieve. I think in many cases we shall get up to higher than 8 kc/s, and in the case of the local transmitters up to the full frequency range.

As regards Mr. Lett's remarks on using equalizers, this is rarely possible because, in the present network, loaded lines act as low-pass filters and above the cut-off frequency of the filter no amount of equalization will bring back what is virtually not there. If the line is not loaded, the type of plant available to-day is such that if you try to equalize it beyond a certain frequency you find your transmission well down in the line noise.

Mr. Lett assumes that about 80 per cent. of the listening public get adequate service up to 5 kc/s at present, and therefore we cannot justify the increase in price unless it can be demonstrated that there is a worthwhile improvement in quality from the new receivers. We do not consider it is our duty to provide a spectacular increase in quality for this 80 per cent. of listeners, but rather to provide for the listeners who get a poor service and for those who get even none at all.

One of the great merits of the f.m. system is undoubtedly the noise-free background of listening but I fear that with the improvement in radio reception conditions listeners will become increasingly aware of line noise. Ringing and dialling, teleprinters, facsimile transmissions, remote control devices, etc., all contribute their quota of noise, and I think we shall have to face an increased volume of complaint from listeners.

On another aspect of noise, Dr. Sturley referred to the expansion of the dynamic range of the programmes and suggested that it might be possible to expand from the present 25 db range. I think that is very doubtful at present: we cannot increase power because of the Post Office restrictions and we cannot reduce it because of line noise. I commend this point to the attention of the G.P.O.

W. M. Dalton (*Associate Member*): Frequency modulation has been boosted as providing high fidelity sound and unless this is present, what else will sell such receivers? If we are going to provide 8 kc/s, we need also to go down to 63 c/s to provide balanced reproduction. This means better smoothing, better i.f. and a.f. stages. In addition to a second i.f. or r.f. valve and three i.f. transformers, a tuning indicator or a.f.c. is necessary. Incidentally a.f.c. might be cheaper in that a lower stability oscillator could be used. I.F. switching is not necessary if the 465 kc/s i.f. transformers are used as decoupling for the 10 Mc/s i.f. transformer.

Due to this increase in cost, I do not think that an m.f./v.h.f. receiver will sell readily. Probably a combined v.h.f./television receiver, using the same i.f. transformers, would be preferable.

L. G. Woollett: Can Mr. Holmes give us an assurance that the line from Broadcasting House to Wrotham will at least be capable of taking 20 kc/s? I say 20 advisedly, because I think 15 kc/s is insufficient.

With regard to the Sutton Coldfield transmitter, would it be possible for the B.B.C. to use a receiver in the first class service area to take the transmission from Wrotham instead of using Post Office lines? I realize this method could not be used for great distances. For instance, you could not go to Scotland in this way, but surely it would be possible for the whole of Southern England to be covered without the use of Post Office lines?

It should be remembered that there is a very big difference in distortion between the ratio detector and the properly adjusted Foster-Seeley detector. Although this may not matter for ordinary commercial sets, in the case of high fidelity equipment I contend the Foster-Seeley detector is the right one to use. In addition to this the Foster-Seeley discriminator can be used to provide a control voltage for an a.f.c. stage.

J. H. Holmes (*in reply*): As far as we know the frequency band capable of being transmitted to Wrotham is about 15 kc/s in the case of the Home Service, about 13 in the case of the Light and 12 in the case of the Third.

F. R. Yardley (*Associate Member*): The average listener who acquires an f.m. receiver will not enjoy the high quality service which he could obtain on a wire-broadcasting system. The latter type of service does not suffer from distortion, which I understand is inevitable even by direct reception by v.h.f. and f.m. methods; and furthermore it does not suffer from interference which may be introduced via the ether on an f.m. service. Whilst not wishing to decry the introduction of an f.m. service, with all the benefits which will still not make it 100 per cent. perfect, one wonders whether the B.B.C. is not a little late in the day in introducing a new type of service to give improved reception, particularly as the even better method of wire broadcasting has long been the vogue.

As the advent of an f.m. service is now an established fact, there are two small points concerning receiver design which are worth comment.

Most of the v.h.f. f.m. receivers which are now available to the public still have to be tuned by the listener. Personally, I would prefer some form of pre-set tuning, as we have in a television receiver, but it is probably a question of frequency drift. However, simplification of the tuning would ensure that the receiver tuning is not left in the hands of the listener. Very few people know how to get the best performance out of a receiver.

One further point which is of importance is the fact that receivers are still being provided with medium and long wave a.m. facilities. Would it not be desirable to dispense with these right away in the interests of cost, or do the radio manufacturers still have some misgivings and consider that the f.m. service is still not likely to provide all that it is claimed to provide?

E. L. E. Pawley: In his opening remarks, Mr. Lett calculated that the number of people who are at present dissatisfied with medium wave reception was about 20 per cent. I think that is just about the right figure in relation to the Home Service for the country as a whole, although in Wales the figure is very much higher. But he spoke as if it was a relatively low figure that we need not worry very much about. I can assure him that 20 per cent. represents more than two million licence holders—a very large number indeed!

We calculate in the B.B.C. that, when the whole of our v.h.f. plans are completed, 98 per cent. of the population will get good service on all three programmes, which is very much better than we can do at present.

Mr. Holmes referred to the fact that the Postmaster General does not allow the B.B.C. to use its own v.h.f. links for permanent connections between stations. But it is possible, as another speaker suggested, to pick up a transmission and re-broadcast it from the local station. That will be possible in some cases, but not in all. One has to be careful to avoid the position in which the failure of one station would put a whole chain of stations out of action.

On the question of bandwidth, it seems to me that people are much more conscious of a positive evil than of a negative good, if I may put it that way; and what they complain about is anything extraneous, i.e. interference. To a lesser extent they complain of distortion, and to a lesser extent still of not having the last octave. There is, of course, a recrudescence of interest in wide-band high-fidelity broadcasting, and that is certainly all to the good and to be encouraged. But the great thing is to get rid of the interference from foreign stations and the other sorts of noise to which long and medium wave-lengths are at present subject. When we have done that and gained some improvement in bandwidth (because the bandwidth of receivers will not have to be so tightly restricted) then will be the time to think of widening the bandwidth of the transmission. One must say that at first the transmissions will not all do full justice to the top response available in the receiver, but I would ask whether one can be certain that, at the lower end of the scale, the receivers will do full justice to the transmission!

Little has been said about receiving aerials; the sensitivity of the v.h.f. sets that are being designed is such that many people will not get satisfactory reception with indoor aerials or with aerials incorporated in the receiver. In the fringe areas outdoor aerials will be necessary, and the exact placing of those will be important where multipath reception is met. Mr. Brinkley mentioned the question of spurious frequencies from the three-transmitter stations; it is an important point that is being watched. Some tests have already been made and more will be made later. The tests to which he referred were carried out when the station at Wrotham was not in its final condition.

Mr. Yardley referred to wire broadcasting services as if there was almost a spirit of competition between them and radio frequency broadcasting, but in the B.B.C. we do not feel that at all. We regard the two things as being complementary.

A. J. Jackman: The General Post Office has to supply underground plant for quite a range of frequencies: we provide 3-4 kc/s for trunk communications; the figure of 8 kc/s for broadcasting has been mentioned and we have at least one route which gives us 16 kc/s; carrier systems use 48 kc/s or 96 kc/s; and then the co-axial cable range runs into megacycles. We have, however, to plan cables for a trunk telephone system and it works out generally that a cable scheme comes into being some six years or more after it is first planned. That cable is then expected to have a fairly long life.

The G.P.O. is granted capital for this work, so we are rather handicapped in providing things other than the public trunk service. We can make some provision for "music" circuits which the B.B.C. is able to use. As an example of this Dr. Sturley showed a map of v.h.f. transmissions on the west coast of Wales; last year new cable schemes were completed all round the south coast by Cardiff and Swansea and up the west coast, and also across central Wales. Any demand for a circuit of greater bandwidth must thus be met by the plant which we have available.

Mr. Holmes referred to loaded cable pairs. We put in loading coils at regular spacing, getting a reduced bandwidth, but we are able to space out amplifiers a long way apart: these circuits find considerable favour with the user because they have comparatively low fault liability. We have other circuits where the amplifiers are as close together as 14 miles apart, and they do not find so much favour with renters.

In general terms, methods of increasing bandwidth with existing plant result in bringing the amplifiers closer together. This may mean a new design of amplifier so that more stages do not give poorer result. But we need to think fairly carefully as to whether more amplifiers more closely spaced are going inevitably to give more faults. As Mr. Pawley pointed out, what annoys the listener most is not so much restricted bandwidth as faults which cut him off altogether.

P. Scadeng (*Associate Member*): V.H.F. broadcasting, whether it be a.m. or f.m., offers among other advantages that of extended audio frequency response; but f.m. broadcasting has the advantage over a.m. of being able to increase the dynamic range due to its constant amplitude transmission characteristics. I therefore feel it would be indeed a pity if endeavours were not made to take advantage of it. I believe that limiting on a.m. is confined to the upper amplitude excursions, therefore without going down into the noise spectrum at the lower end, it ought to be possible—even if it means duplicating the programme controllers—to produce a wider dynamic range for the enthusiast.

Secondly, difficulties in the design of battery f.m. receivers are mainly the result of putting a v.h.f. range on such receivers; only a relatively small extra complexity is involved in making this v.h.f. range frequency modulation.

As engineers, we are concerned with the possibilities of increasing the frequency response of our receivers, and we are all concerned with the upper register, since that is the main acoustic advantage of v.h.f. The restricted acoustic range of small radio receivers is indicated mainly by the need to obtain a satisfactory tone balance within the limitations imposed by the cabinet when considered as an acoustic box, and only to a small extent by the desire to cut down whistles. The average user will hardly appreciate an increased upper register in his small radio.

One of the other advantages that has not been mentioned is that obtained when tuning on f.m. At the moment we have only two experimental transmissions, and have been able to get the two programmes very easily. By contrast, on the medium wave band, if you were to remove the calibration from the tuning dial, you would find it extremely difficult, quite apart from the whistles, to find even the Light, Home and Third programmes. The average person will find a wonderful difference when tuning on the v.h.f. band in the ease with which these three programmes can be obtained with no noise or interference.

L. Driscoll (*Associate Member*): Multipath reception, causing amplitude modulation due to interference between the waves coming by different paths, can produce considerable distortion unless very good limiting is employed in the receiver: and I do not think ratio detectors are good enough limiters. If, however, an extra i.f. valve acting as limiter is added in front of the ratio detector, the rejection of amplitude modulation is much improved, and distortion due to multi-path reception made negligibly small, as far as can be ascertained from our few experiences of it.

We have found the phenomenon spread over some square miles at Rainham in Kent, and have also met it between Royston and Baldock. It would be useful to know of other places where multi-path reception occurs, with a view to carrying out experiments.

A. G. Wray (*Associate Member*): After experience in designing f.m. test equipment I have come to the conclusion that in a number of respects this is simpler and easier than designing for corresponding a.m. conditions. I feel that receiver manufacturers, too, will find this to be true when they have gained more experience in f.m. set production.

As an example to illustrate my point, in amplitude modulation we have an absolute limit set for us by a depth of 100 per cent. If you try to exceed this figure, much distortion will result. In f.m. there is no such limitation: 100 per cent. modulation depth is set at some arbitrary figure. If, by chance, over-modulation now occurs by a factor of, say, 10-20 per cent., little noticeable distortion will be introduced. No difficulty should be experienced in ensuring that an f.m. receiver responds faithfully up to this 20 per cent. over modulation limit. This becomes increasingly evident when considering the design of suitable detectors. In a.m. detector circuits great care has to be taken when the modulation depth approaches the 100 per cent. figure. On the other hand, frequency modulation detector circuits are free from this limitation; no fixed modulation depth is purely a function of the design parameters chosen.

Thus, it can be seen that f.m. has certain advantages to offer which may help to simplify design and perhaps, in the long run, ensure that the f.m. receiver be produced for the same price as its a.m. counterpart.

C. A. Marshall: The basic problem to be faced is that lines are not suitable for high fidelity music transmission; certainly this applies to the G.P.O. lines. We might find a partial solution by setting up a microwave link system in parallel with the existing trunk lines. The B.B.C. found it necessary to use microwave links for television, and there is also a fairly good coaxial cable system running over a large part of the country which can be used for television. Can we not get all our broadcast programmes centred on this coaxial link by using a microwave interconnecting system?

F. T. Lett (in reply): I agree with most of what Mr. Burnard, the first speaker, has said. Mr. Brinkley wanted to know where we could export a.m./f.m. sets to, and I think the answer is that there has been no hope of any north European market until we could supply a.m./f.m. sets. Whether there is hope when we have these sets available is purely a question of economics.

With regard to Mr. Holmes' remarks, I am delighted that the London Home Service will have 15 kc/s, the Light Programme 13 kc/s, and the Third 12 kc/s. These figures are better than I had been led to believe. I think that we should know how much money is actually involved in increasing all these line bandwidths up to 15 or 16 kc/s. It may double the cost of the line but is that high compared with the overall cost of the transmission?

I note that Mr. Dalton puts the cost of an a.m./f.m. set at 50 per cent. more than the normal a.m. set—I think that this is too high. With regard to going down to 60 c/s in the bass response, that is all right with a big console floor model but I do not see how you attain this in a small table model. I do not think even if the bass response of a model only goes down to, say, 150 c/s then it is still worth going up to the higher frequencies.

Referring to Mr. Pawley's remarks, when he agrees with me that only 20 per cent. of the listeners really need this f.m. service for interference reasons, it would be an awful thing for industry if it had to provide two ranges of receivers—one range for a.m. and one range for a.m./f.m. In order to keep the cost of the sets low one has to spend an enormous amount of money on tooling, etc., and the overall cost of the set is obviously only low if tooling is spread over a large production.

Regarding the Foster-Seeley detector, I agree with the remarks of Mr. Woollett where high grade, expensive equipment is involved but I do not agree that the slightly improved harmonic performance of this detector is worth the extra cost for the normal domestic table model.

Dr. K. R. Sturley (*in reply*): In answer to Mr. Jenkins, it is planned to provide Wales at an early date with a v.h.f. service and there will be three transmission sites—at Wenvoe, Blaen Plwy, and Penmon. A large proportion of the Welsh population will then be provided with adequate coverage of sound programmes. Mr. Brinkley indicated an important problem, intermodulation products of the three programmes, but this will I am certain be solved.

Mr. Holmes stressed the limiting effect of noise on lines and took me to task over the matter of increasing dynamic range. I was fairly guarded in my comments and did specify that artistic considerations must be taken into account because a range greater than 25 db may be unpleasant in a normal living room.

Mr. Pawley is right to urge the importance of economics. Most engineers will appreciate the need for keeping costs down but the general public does not always understand that the B.B.C. has to operate on a limited budget.

The Chairman: The subject which has been mentioned more often than any other is that of the frequency range of the proposed new transmission, and I do hope that the B.B.C. are not going finally to close the door to the request that they should make use of the full frequency range, even if this could only be done on one of the three programmes. My very rough estimate is that the cost of doubling the frequency band of one programme on a national basis would be under £100,000 per annum, which though a large sum of money is very small compared with the total to be spent on this scheme.

I would like to draw Mr. Brinkley's attention to the fact that frequency modulation transmitters have been operating in Jamaica for some years now. It has been extremely difficult to get any British manufacturers to send any sets there, so there is great difficulty in equipping the population with receivers. I would strongly advise that as a place for future exports.

Recent Exhibitions

INSTRUMENTS

Electronic instruments made up a large proportion of the exhibits at the British Industries Exhibition, held at Earls Court, London. Devices associated with the latest trends in automation were demonstrated, and included electronic computers suitable for operation in conjunction with process controllers. There was a wide variety of indicating instruments employing many different techniques. A typical example was the continuous measurement of the thickness of sheet material either by capacitance methods or radio-active means.

Stands showing the work of industrial and Government research laboratories provided pointers to the methods to be adopted in the future.

One of the most interesting of the D.S.I.R. exhibits was that by the National Physical Laboratory which consisted of a compact delay line of high stability using torsional waves; these travel along about 60 ft. of 0·040 in. wire coiled up inside a drum. The device, which uses barium titanate transducers, is considered to have advantages over the similar mercury delay line and is in particular much smaller and cheaper. For a bandwidth of about 1 Mc/s it has a delay time of $6\frac{2}{3}$ msec. which gives a comparable storage capacity to a typical mercury delay line having a bandwidth of about 6 Mc/s and a delay time of 1 msec.

PLASTICS

At the British Plastics Exhibition held at Olympia, London, a number of exhibitors showed typical radio components which ranged in size from complete cabinets down to insulating sleeving. Plastic sheet backed with metal and suitable for use with one or other of the printed circuit techniques, was another item of interest to radio engineers.

Other parts of this Exhibition dealt with equipment for the fabrication of plastic components and several firms showed radio frequency heaters and welders. The majority of these, which cover a very wide range of output powers, operate at frequencies in the region of 35 Mc/s and in general development is towards achieving greater ease and speed of operation.

OFFICE EQUIPMENT

The applications of electronics to be seen at the Business Efficiency Exhibition fell into the category of computation, communication, and recording. Business type computers have been dealt with fairly fully in the Institution's *Journal* in the past year and the Exhibition showed the realization of many of the techniques which have been described. More efficient communication is becoming important both within a large concern and between widely separated firms, and ways of achieving this electronically either by facsimile methods or by teleprinting were demonstrated.

Magnetic recording has made enormous strides in recent years in its application to dictating and recording equipment and a wide range of machines was to be seen. These make use of recording on tape, wire or disk, and emphasis is laid on the ease of play-back.

PRINTING

Far reaching advances are currently taking place in the printing industry and, as elsewhere, electronic techniques are being called upon to an increasing extent. In the actual operation of printing presses electronic speed control gear has been in use for a number of years and some of the latest developments were to be seen at the International Printing Machinery and Allied Trades Exhibition held at Olympia, London. Multi-colour printing processes now rely very largely on the automatic control of the registration of component colours by photo-electric cells and associated servo-mechanisms.

In the allied field of the engraving of illustration blocks a process similar to electronic facsimile picture transmission has been evolved whereby photographs or line drawings may be etched directly on to plastic sheets by a heated stylus: small parts of the plate are burned out to varying depths according to the strength of impulses emitted by the scanner. One of the three processes demonstrated enables the finished block to be of a different size from the original. In another machine the "scanning" was effected with a reciprocating movement in the horizontal plane (rather like the scanning of a television picture), instead of on a rotating cylinder as used in other patterns.

A MERCURY DELAY LINE STORAGE UNIT*

by

R. D. Ryan, B.Sc., B.E.†

SUMMARY

A description is given of a storage unit for an electronic digital computer. Mercury delay lines are used as the storage elements and their construction and operating characteristics are discussed. Information is stored in binary form by keeping pulses circulating around a loop which includes a mercury delay line. The electronic circuits associated with this loop are also described. Finally a method is discussed of interspacing the pulses of one loop between those of another loop and so doubling the storage capacity.

1. Introduction

The storage unit described in this paper forms part of an electronic digital computer at present in operation at the C.S.I.R.O. Radiophysics Laboratory.[1] In principle this machine is similar to a number of overseas computers such as the EDSAC.[2,3]

The unit provides storage for 1,000 numbers of 20 binary digits—equivalent to 6 decimal digits. The time taken to read a number into or out of the store, called the access time, is approximately 1 millisecond. This access time largely determines the speed of computation.

In designing a high speed store for a computer it is necessary to strike a compromise between the conflicting requirements of large storage capacity and small access time. An inadequate amount of storage makes the programming of problems difficult.

Another important requirement is extreme reliability, since an error in a single digit over a period of hours may ruin a lengthy calculation. It is also desirable to keep the amount of equipment to a minimum.

The design of the computer, which was started in 1948, was based on the mercury delay line type of storage as this was the only satisfactory system which had been developed at the time. Since then, the Williams' electrostatic cathode-ray tube storage system has been developed and is being used in some overseas computers. This system has the advantage of a small access time of 20 microseconds or less.

A somewhat slower magnetic drum store[4] is also used to augment the storage capacity of the Radiophysics computer.

2. General Description

The computer is of the serial type, i.e. the digits of a number follow serially one after the other along a single digit trunk, as compared with a parallel machine where all digits appear simultaneously on a number of trunks.

The numbers are stored in binary form and "ones" are represented by positive digit pulses of 1 microsecond duration, 50 volts amplitude and spaced 3 microseconds apart. These are grouped into "words" or numbers of 20 binary digits each occupying a period of 60 microseconds. These words are both the operating instructions and the numbers operated on by the computer.

The method of storing these numbers is to keep them circulating around a loop which includes a delay line whose delay is greater than the time occupied by the digits being stored. Then, as each pulse arrives at the delay line output, it is passed back to the input and so may be held in the loop indefinitely. To prevent progressive distortion of the circulating pulses and to keep them in synchronism with the rest of the computer, each pulse is passed through a clocking gate before going into the line again. The output of this gate has constant pulse shape and timing.

A block diagram of a storage loop is shown in Fig. 1, including gates for reading information in and out and for clearing. The symbols used are explained in Appendix 1 and Fig. 9.

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To obtain the required storage capacity, a number of loops are used. The clock, input, output and clear trunks are common to all loops but each loop has a separate line selector input by which the computer selects which loop is to be operated on at any particular time. Thus to read in, the input trunk is activated with the appropriate digit pulses and a line selector signal opens the coincidence gate of one loop to allow these pulses to pass into the buffer stage, and then to the driver chassis where the pulses modulate a 10 Mc/s carrier. These r.f. pulses are applied to the X-cut quartz crystals of the mercury delay line and transformed into ultrasonic waves in the mercury. After a delay depending on the length of the mercury column, these waves reach the crystal at the other end and generate pulses of 10 Mc/s r.f. These are then amplified, detected, again amplified in a video stage and passed back to the circulator chassis. There the pulses open a coincidence gate to allow a standard clock pulse to pass through into a short electrical delay line, through a clearing gate into the buffer stage and so around the loop again.

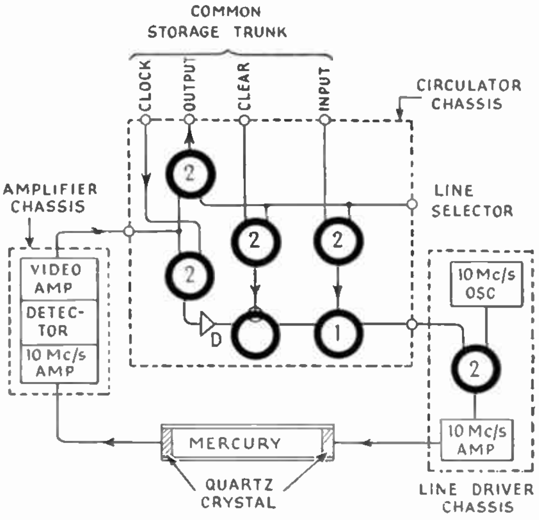

Fig. 1.—Block diagram of storage loop.

Clearing is performed simply by preventing circulation through the inhibit gate. The short delay D is inserted in the loop between the output and input coincidence gates so that pulses read out of the store on to the computer main digit trunk will be in the same time position as the pulses that are read-in. There are always some delays, of the order of 0·1–0·2μsec., in passing through gating circuits. These delays are additive and without D would produce a difference between input and output pulses of 0·5 μsec. With D in the circuit, the pulses applied to the output coincidence gate are early, but the delays encountered between here and the main digit trunk bring them into the correct position. The delay line D is also essential to a system of interspacing, which is described in Section 6.

The reading out of information in the store has no effect on circulation; the information is stored indefinitely unless actually cleared out. However, one defect of all dynamic storage of this nature is that a power failure causes the loss of all information stored. This is not the case with the magnetic drum type of store.

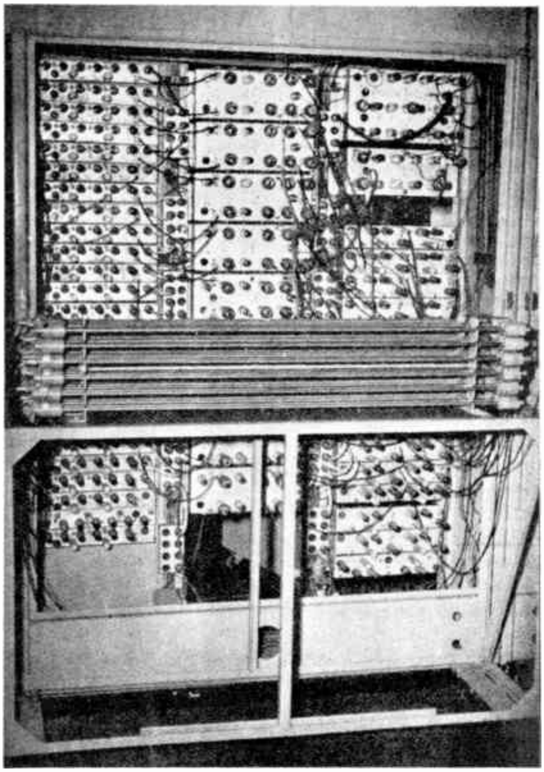

Fig. 2.—Arrangement of the storage cabinet.

It would clearly be too expensive to use a separate loop to store each of the 1,000 numbers

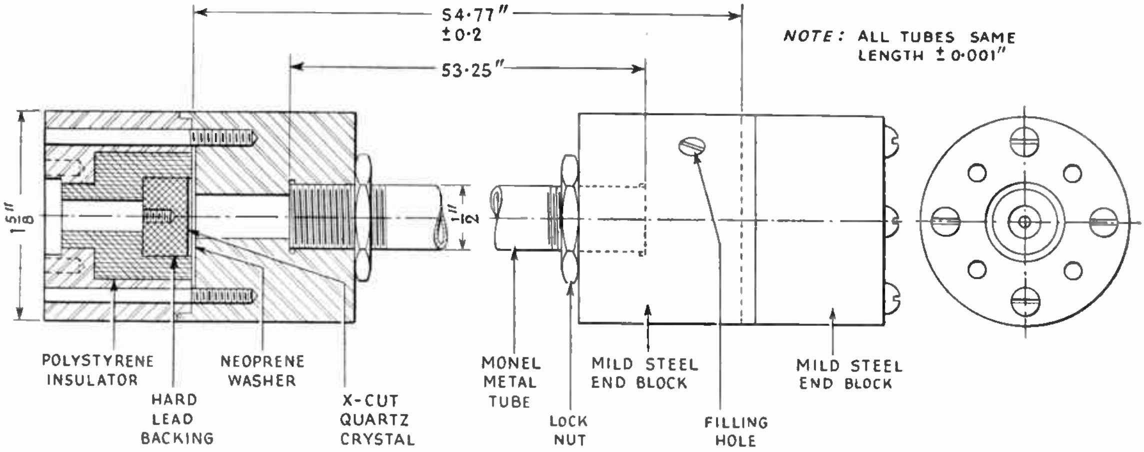

Fig. 3.—Mercury delay line.

required for general computing work. The more numbers stored in each loop, the less the amount of equipment needed. However, the mercury delay lines cannot conveniently be made much longer than 5 feet. A more important consideration is that, while the numbers are passing along the delay line, they cannot be read out. When the computer requires a number, it has to wait until it appears at the output. Thus the number of words stored in each loop determines the access time, and so the basic speed of the computer.

In the Radiophysics computer, 16 words, i.e. 320 digits, are stored in each loop. This requires a 54-in. delay line with a delay of 960 microseconds and enables the 1,000 words to be stored in 64 delay lines, or their equivalent. The number 16—a power of 2—was chosen for ease of coding in the computer. The average access time is 480 microseconds.

The arrangement of the storage unit cabinet is shown in the photograph of Fig. 2.

3. Mercury Delay Line Construction

The mechanical construction of the mercury delay line is shown in Fig. 3. The crystal is seated on a hard lead backing which is inserted in a polystrene insulator. A neoprene washer protects the face of the crystal when it is pressed between the two mild steel blocks to form the complete end cell. These end cells are screwed on to the Monel metal tube and locked into position by nuts. No special seal is required between the tube and the end cell. The line is filled with mercury through the filling holes in each end cell.

The active diameter of the crystal, in contact with the mercury column, is $\frac{11}{32}$ in. The mercury itself is at earth potential and the r.f. voltage is applied to the back of the crystal through the lead.

To obtain good acoustic coupling between the quartz crystal and the mercury, the crystal is given an optical finish, is carefully cleaned by washing in hot chromic acid, then in carbon tetrachloride and distilled water, and is finally dried on clean filter paper. The acoustic coupling into the lead backing is improved by a film of glycerine, which excludes the air.

In assembling the delay lines, care must be taken to see that all parts in contact with the mercury are clean and free from grease. Any dirt reaching the face of the crystal increases the attenuation and quickly makes the line unusable. Initially, mild steel tubing was used to hold the mercury column, but it was found too difficult to clean properly, due to the rough inside surface. Monel tubing has a good smooth finish and is readily cleaned by pulling rags soaked in carbon tetrachloride through the tube a number of times and finally rinsing with clean fluid. Glass tubing was not tried, in view of its fragility and the expected difficulty of fabrication with the required accuracy.

It is notoriously difficult to keep mercury clean, and it has been our experience that the average life of a delay line between cleanings is about two years. The source of the scum that gradually collects at the crystal face is not as yet known. It could be the Monel tubing; this showed a small amount of pitting and as a result the inside of the tubes is now lacquered before assembly. Another possible source of the scum is the neoprene washers resting against the crystal face. These are also carefully cleaned before assembly.

The assembly and servicing of the delay lines is somewhat simplified by using a number of separate delay lines, rather than some composite or tank arrangement. A defect in any one line can be rectified without dismantling a whole group of lines and so putting the computer out of service for a period. The only difficulty with separate lines is to obtain lines with exactly the same delay, which is necessary since all lines must work together in synchronism. To achieve this, a standard length was made up, and all lines were made to exactly this length with a tolerance of 0·001 in. The exact value of the standard length was not of importance, since the frequency of the digit pulses was readily adjusted to the value required to keep the delayed pulses in correct synchronism.

As the delay of the lines varies appreciably with change in temperature, all delay lines must be maintained at the same temperature within 1° C, although not at a constant temperature. To this end, all the delay lines are mounted close together in a thermally insulated box, so that temperature changes within the box, such as occur when switching on, will be so slow that all lines will change together. As can be seen from Fig. 2, the box of delay lines is placed close to the storage cabinet. This allows the connecting cables to the delay lines to be kept short.

The computer also uses a number of short delay lines, one word long (60 μ sec.), in the arithmetic part of the computer. They form part of the registers in which numbers are stored while being operated on by the computer. These lines are similar to the long ones; in fact the same parts are used for the end cells, and the only difference is the use of a shorter tube.

4. Mercury Delay Line Characteristics

When the pulse r.f. voltage is applied to the piezo-electric, X-cut quartz crystal, it vibrates in a thickness mode, and being in contact with the mercury on one side, it starts an ultrasonic wave packet travelling through the mercury with a velocity of $1{\cdot}45 \times 10^5$ cm/sec, which is equivalent to a delay of 17·5 μsec/in. Arriving at the receiving end of the line, this wave sets a second crystal vibrating, and so develops a corresponding pulse of r.f. voltage across it. This delayed pulse is attenuated and distorted.

Unfortunately, a property of the piezo-electric effect is that, in addition to attenuation of the ultrasonic wave in the mercury, there is a loss of roughly 50 db between input and output voltages. This brings the output into the millivolt region and a well shielded amplifier is required to prevent interference pick up, which would destroy the information stored in the memory loop.

Distortion of the output pulse occurs if the bandwidth of the delay line is limited. One reason for the use of the mercury delay line in the memory system is that by suitable design quite large bandwidths (over 10 Mc/s) can be obtained. Water and solid delay lines, while more convenient for some purposes, are more limited in bandwidth. A wide bandwidth is needed to maintain the shape of the digit pulses and so keep each digit distinguishable from its neighbours.

The wide bandwidth of the mercury delay line is due (*a*) to the large damping imposed upon the crystal vibrations by the mercury loading, and (*b*) to the propagation characteristics of the ultrasonic waves in the mercury. The mercury damping causes the crystal vibrations to build up to full amplitude and fall to zero amplitude within less than one cycle of oscillation of the natural resonant frequency. This is necessary since a one-microsecond pulse of 10 Mc/s r.f. contains only 10 cycles in all.

As regards (*b*), a theoretical analysis[5] of the mercury delay line shows that the ultrasonic waves in travelling through the mercury may also undergo distortion equivalent to that introduced by a band-pass filter. The effective bandwidth of the line increases with the factor a^2f^3/l, where l is the length, a the radius of the mercury column, and f the frequency of the ultrasonic waves. As an example, a line 55 inches in length (delay 960 microseconds) with a diameter of $\frac{3}{8}$ in. operating at 10 Mc/s, has a calculated bandwidth of 2 Mc/s. Actually this analysis is conservative and the effective bandwidth, as indicated by the rise time of the output pulses, is greater than this.

In designing a line, the length l is fixed by the delay required. It is convenient to keep the diameter small ($\frac{1}{4}$ to $\frac{1}{2}$ in.), since this reduces the amount of mercury required. However, apart from these considerations, it is clear that the bandwidth of the line is mainly determined by the ultrasonic frequency, since it is a function of the cube of the frequency. Against this increase in bandwidth, however, must be debited an increased attenuation, which is proportional to the square of the frequency and becomes appreciable (1 db/ft) above 10 Mc/s.

Another important factor which must be considered in determining the operating frequency is the amplitude of the echo signal which may be obtained. When the pulse of ultrasonic energy reaches the receiving crystal, some of it is reflected back along the line, is again reflected at the transmitting crystal, and so produces another echo signal at the receiving crystal. This process can continue for some time producing a series of echoes spaced at intervals of twice the line delay, as shown in Fig. 4. When the delay line is used as a store, any appreciable echo is undesirable, since it will give rise to spurious pulses.

One advantage of using mercury as the ultrasonic delay medium is that its acoustic impedance ($19{,}800\Omega/\text{cm}^2$) is close to that of quartz ($15{,}000\Omega/\text{cm}^2$). Thus, there is very little reflection of acoustic energy at the quartz mercury interfaces. The amount of reflected energy, therefore, depends upon the acoustic match between the crystal and its backing. The energy must, of course, then be absorbed in the backing.

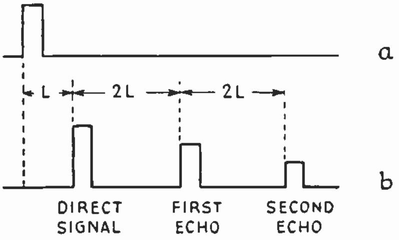

Fig. 4.—Delay line echo signals.
(a) Input signal.
(b) Output signal.
L is the line delay.

The best match is provided by mercury backing and this has been widely used. However, the crystals, which are quite fragile, are not firmly supported and are liable to fracture. Another method of obtaining the same result is to use some solid material, such as hard lead (93% lead, 7% antimony), as a backing to the crystal. While the lead is not as good an acoustic match as mercury, it is still adequate to produce a low echo level. If the crystal is simply pressed into contact with the lead, the air film prevents good acoustic contact. A film of glycerine is found to exclude the air and provide a fair acoustic contact.

It should be remarked that prevention of echo signal in this way by the use of an absorbing backing to the crystal reduces the signal level by 12 db. This is due to the loss of 6 db at each end cell, one half of the energy being dissipated in the backing.

An alternative method of eliminating the echo signal is to use an ultrasonic frequency high enough to produce an attenuation of 20 db in the mercury column. This brings the first echo 40 db below the direct signal, which is adequate to prevent interference. For a 5-ft. delay line this would require a frequency of 15 Mc/s. There is not much to choose between the two methods, but in the Radiophysics computer it was decided to use a frequency of 10 Mc/s and absorbing end cells of hard lead.

Another important advantage of mercury as a delay medium is its small variation of delay with temperature (+ 0·03% per ° C.). For a 960-μsec. delay line, this amounts to 0·3μsec. per ° C., so that for ordinary room temperature variation, the change in delay is still appreciable. Unless corrected, this would be enough to cause loss of synchronism between the delay lines and the computer clocking pulses.

Whilst it would be possible to maintain the delay lines at a constant temperature, it is less trouble to vary the frequency of the clock pulses, so as to maintain correct synchronism. This is done automatically by using a separate delay line to control the frequency of the clocking pulses.

The theory of the mercury delay line indicates that the output signal amplitude depends, rather critically, on exact alignment between receiving and transmitting crystals within an angle of 1 deg. In fact, we have found that the line can be flexed up and down over 1 inch (corresponding to 4 deg.) between crystal axes, without noticeable change in signal amplitude.

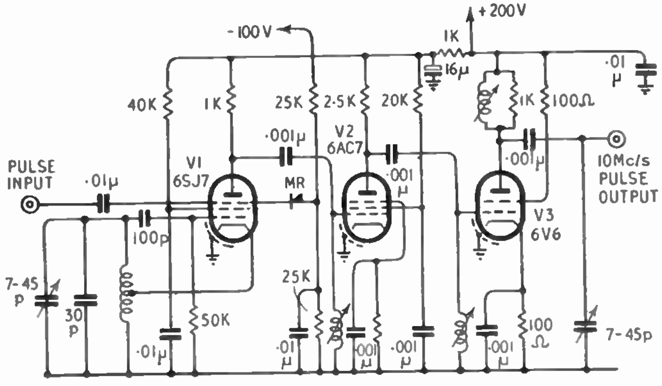

Fig. 5.—Circuit diagram of the line driver unit.

This may be attributed to the guiding effect of the narrow tube on the ultrasonic beam.

5. Storage Circuits

5.1. *Line driver*

This circuit, shown in Fig. 5, converts an input video pulse of 50 volts amplitude into a pulse of 10 Mc/s r.f. of 30 volts peak-to-peak amplitude suitable for driving the quartz crystal. The screen, grid and cathode of V1 operate as an ordinary 10-Mc/s Hartley oscillator, while the suppressor biases the anode current to cut-off. The input pulse removes this bias and allows a corresponding pulse of 10 Mc/s current to reach the anode circuit. This is then amplified, the tuned circuits being arranged as a staggered triple, and the output applied to the delay line. No matching circuits are used at the delay line input or output; the gain obtainable was not considered to be worth the trouble required to obtain good matching over the required bandwidth. A variable capacitor is connected across the line driver output to compensate for the different lengths of the coaxial cables connecting the drivers to the delay lines.

The suppressor cut-off characteristic of the 6SJ7 is such that there is very little variation of the r.f. output pulses for input pulse amplitudes varying between 30 and 50 volts. A few batches of valves have been found to have suppressor characteristics which are different from the general run of tubes and do not give satisfactory performance.

5.2. *Line amplifier*

The r.f. part of the amplifier consists of a staggered quadruple using 6AC7 valves and giving a gain of up to 70 db over the band 7·5 to 12·5 Mc/s. A germanium diode detector drives a shunt-compensated 6AC7 video stage and a 6V6 cathode fol-

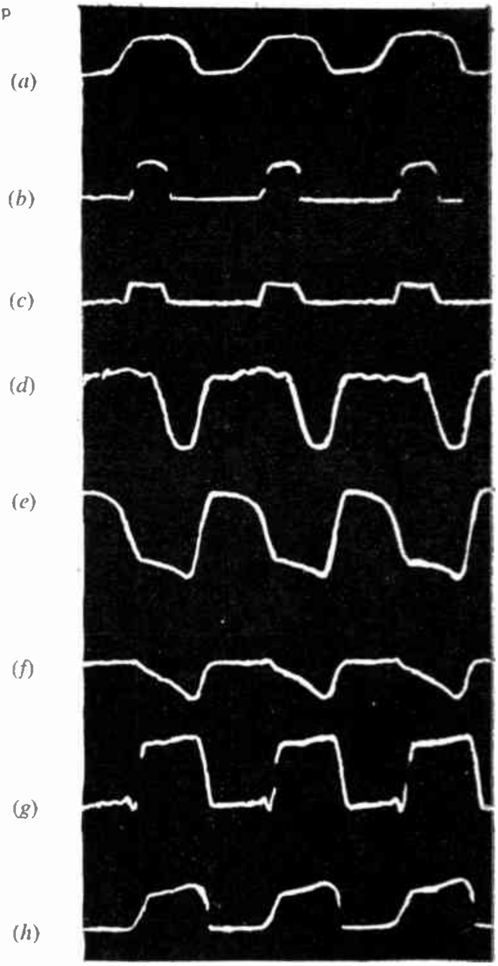

Fig. 6.—Circulator unit waveforms; pulse spacing 3 microseconds.

(a) Amplifier output pulses,
(b) Clocking pulses,
(c) Clocking gate output,
(d) Delay line output,
(e) V2a anode,
(f) V3 grid,
(g) V3 anode.
(h) V4 cathode.

lower is used for the output. Provision is also made for inserting a 0·5 microsecond electrical delay line between the cathode of the 6V6 and the output; this is used to make up for occasional small variations in the delay of different mercury delay lines. The amplifier output waveform is shown in Fig. 6a.

It is not readily possible to incorporate automatic gain control into the amplifier, since in some cases the circulating loop may not hold any pulses, or only a few. It is necessary occasionally to adjust the gain control to give the correct pulse amplitude.

5.3. *Circulator*

This circuit, which is shown in Fig. 7, makes provision for clocking the amplifier output pulses, reading out, reading in, and clearing the numbers stored. Germanium diodes are used in the gating circuits as buffers and d.c. restorers. The KT61 valve was used as an amplifier and as a cathode follower, because of its high transconductance and current capabilities.

The circuit operation is as follows. The line-amplifier cathode-follower output is connected directly to MR3 and gates the clock pulses applied to MR4 through the common storage clock trunk. These gated clock pulses, shown in Fig. 6c, are amplified in V1 and then delayed in the electrical delay line, whose output is shown in Fig. 6d. They are then broadened in a cathode coupled amplifier, V2a and V3. It is necessary to broaden the pulses to obtain the best possible tolerance on pulse shift at the clocking gate. The broadened pulses are applied via buffer diode MR12 to the cathode follower V4, whose output is connected to the line driver (Fig. 6h).

The input and output gates are conventional; the output of the clearing gate switches V2b on, and so holds the anode of V3 down, if V3 is cut off by circulating pulses.

6. Interspacing

The basic difficulty with all practical storage systems is their limited capacity. For this reason, any method of increasing capacity without a corresponding increase of equipment is worthy of consideration.

The spacing between digit pulses was set at 3 μsec. so as to obtain reliable operation of flip-flop and gating circuits, using ordinary octal-based valves (e.g., 6SN7, 6V6). However, the bandwidth of the mercury delay line is such that much closer spacing of pulses is possible. With this in mind, the storage unit was designed to work with a pulse spacing of 1·5 μsec. so that two storage loops (as seen by the rest of the machine) could be interspaced within one

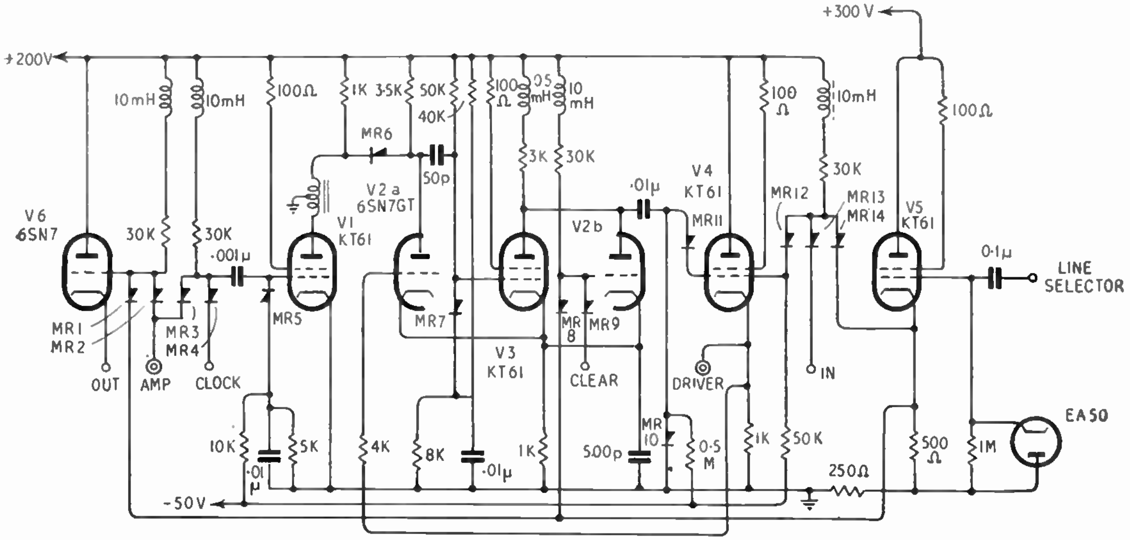

Fig. 7.—Circulator unit circuit diagram.

mercury line. This may be done by delaying the pulses in one loop by 1·5 μ sec. and then combining the two pulse trains.

The block diagram of the input and output gates for an interspaced system is shown in Fig. 8. Pulses appearing on the main input trunk may be gated directly on the storage input trunk or delayed by 1·5 μsec. in delay line X, depending on whether the direct or interspaced line is activated. These pulses are then gated into a delay line loop by the appropriate line selector signal. Thus the direct digit pulses are read into the same position as in the simple system, while the interspaced pulses are placed between the direct pulses.

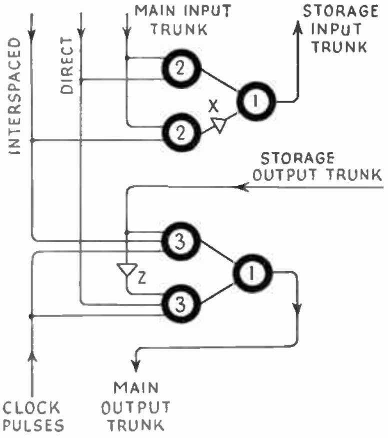

Fig. 8.—Input and output gates for an interspaced storage system.

The delay line D in each storage loop (see Fig. 1) allows the direct circulating pulses to appear at the loop output gate 2 μsec. earlier than the correct pulse position on the digit trunk. On the other hand, the interspaced pulses, which are delayed by 1·5 μsec. in being read in, are only 0·5 μsec. early when read out.

In reading out, the line selector gates both the direct and interspace pulses on to the storage output gates, and through a 1·5 μsec. delay line Z to the other output gate. If the direct pulses are to be read out, then this second gate is activated by the direct signal, while a train of clocking pulses, suitably delayed relative to the clock trunk pulses, allows only the direct pulses to pass out and block the interspaced ones. The delay line Z ensures that the direct pulses are

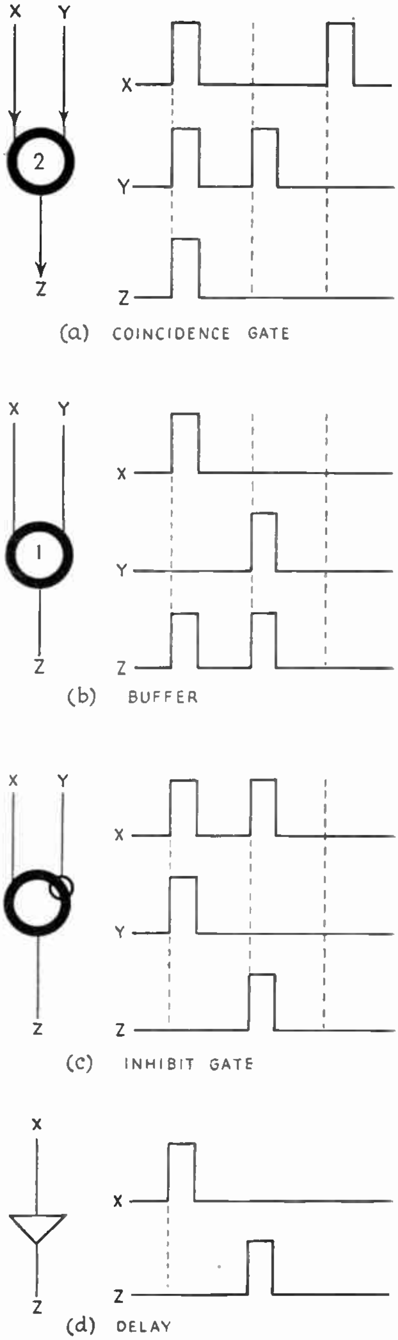

Fig. 9.—Block diagram symbols and the associated waveforms.

in the correct time position when they reach the output digit trunk.

In reading out the interspaced pulses, the first output gate is opened by the interspaced signal, and in this case the pulses let through only the interspaced pulses.

Clearing is performed by gating on to the storage trunk pulses in the correct position to clear out either direct or interspaced pulses, as required.

Such an interspaced system is at present (November 1952) undergoing tests before being put into service.*

7. References

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8. Appendix 1: Block Diagram Symbols

The symbols used in Figs. 1 and 8 are illustrated in Fig. 9, by indicating the waveforms associated with the circuits which they represent. The double coincidence gate shown in Fig. 9a produces an output pulse only when both input lines have pulses on them. Similarly, the triple coincidence gate appearing in Fig. 8 produces an output only when all three inputs are activated.

The "one" gate, or buffer, in Fig. 9b allows either of two inputs to produce an output without interacting back on one another. The inhibit gate of Fig. 9c prevents the passage of a pulse from X to Z, if input line Y is activated. Finally, the symbol of Fig. 9d indicates a delay.

9. Appendix 2: Mercury Delay Line Data

The thickness t of an X-cut quartz crystal is given by:

$$t = \frac{1{\cdot}125 \times 10^5}{f} \text{ inches}$$

where f = resonant frequency of crystal.

Velocity of sound in mercury: $5{\cdot}7 \times 10^4$ in./sec.

Change of velocity with temperature: − 340 parts in 10^6 per ° C.

Delay D in microseconds:

$$D = (17{\cdot}42 + 0{\cdot}0052T)L$$

where L = length of mercury in inches

and T = temperature ° C.

Radiophysics Computer Mercury Delay Lines:

Distance between crystal faces = 54·770 inches.

Delay in mercury at 20° C. = 957 μsec.

Change in delay with temperature = 0·3 μsec. per ° C.

Diameter of mercury column: $\frac{11}{32}$ inch.

Weight of mercury in line: 3 lb.

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* The interspaced system has now been operating satisfactorily for some months, but this paper was written before the author had full opportunity to assess field experience.

GRADUATESHIP EXAMINATION MAY, 1955

FIRST PASS LIST

This list contains the results of all candidates in the British Isles and those of the oversea candidates which were available on July 1st.

The following candidates, having completed the requirements of the Graduateship Examination, are eligible for transfer or election to graduateship or higher grade of membership.

Attew, James Edward. *Weybridge, Surrey.*

Basu, Aniles. (S) *Chelmsford.*
Belcher, John Charles. (S) *Shipley.*
Briggs, Peter George. *London, S.E.*18.

Carey, Henry George. (S) *London, N.W.*10.

Daniel, Henry Asir. (S) *Arborfield.*
Desai, Gajanan Vishnu. (S) *Cambridge.*
Dickin, Frank Douglas. (S) *Great Malvern.*

El-Jadiry, Fakhri Abul Karim. (S) *London, S.W.*18.
Elliott, Alan Tilbury. (S) *Dunmow.*

Harris, Peter Michael. *Sidcup.*
Hatch, Edward. (S) *Belfast.*
Holland, John Philip. *London, S.W.*12.

Jackson, Eric. (S) *London, E.*11.
Jahangir, Mohammad Afzal. (S) *London, N.*4.

Lolayekar, Nagesh Gangaram. *London, W.*3.

Nelson-Jones, Laurence. (S) *Brentwood.*
Newell, Allen Frederick. (S) *Bexhill.*

Oxborough, Frank William. (S) *Swindon.*

Patankar, Atmaram Anant. (S) *Nottingham.*
Peacock, Colin. (S) *Wolverhampton.*
Pittilo, Robert Dawson. *Glasgow.*

Thomas, William James. (S) *Doxey.*
Tribble, Kenneth Alan. (S) *Waihi, New Zealand.*

Walters, Henry George. (S) *Bath.*
Winchcombe, Thomas. (S) *Cardigan.*

The following candidates were successful in the Parts indicated within brackets

Allen, George Edward Elphick. (S) *Chelmsford.* (IIIa).
Asquith, Stanley Francis William. *Hadleigh.* (IIIa).
Atkins, Peter James. (S) *New Romney.* (IIIb).

Beardall, James Howitt. (S) *London, N.*19. (I).
Beckley, Herbert Reginald. (S) *London, N.W.*4. (IIIb).
Bennett, Wilfred Denis. (S) *Stockport.* (IIIb).
Bonner, John Stafford. (S) *West Hartlepool.* (I and II).
Brush, Alberto Valero. (S) *London, N.W.*2. (II, IIIa and IV).

Carlton, John William. (S) *Waterbeach.* (I).
Clarke, Arthur Philip Blake. (S) *St. Davids.* (I, II, IIIa and IIIb).
Clarke, David Kelvin Jenner. (S) *Sutton, Surrey.* (I).
Cole, Horace Albert George. (S) *Swindon.* (I).
Colman, Milton Henry. (S) *Bury.* (II and IIIb).

Darvell, John Louis. (S) *London, N.*13. (I).
Das, Girdebi Kanta. (S) *Surbiton.* (IIIa)
De Ruyter, Albertus Hermanus Maria. (S) *Eindhoven.* (IIIa and IV)
Doyle, Denis. (S) *Limerick, Eire.* (I).

Egan, Michael Gerard. (S) *Dublin.* (I and IIIa).

Fisher, Jack Edward. (S) *Stanmore.* (IIIb)
Fowler, Kenneth James. (S) *London, S.E.*26. (II and IIIa).

Gilbert, Garvin Robert. (S) *Woodbourne, New Zealand.* (IIIa).
Griffith, Douglas Arthur. *Kenley.* (IIIa).

Heal, John William. (S) *Pendine.* (II).
Holden, Dennis George. (S) *Kings Lynn.* (I and IIIa).
Hudson, Harry. (S) *Bradford, Yorks.* (I).
Hughes, John Aledwyn. (S) *London, S.W.*11. (I, II and IIIa).
Hurst, Sydney. *Blackpool.* (IIIb).
Hutson, Geoffrey Henry. *Birchington.* (IIIb)
Hyder, Thomas William. *Southampton.* (I).

Islam, Sayed Sultan-ul. (S) *Sialkot, Pakistan.* (II and IIIa).

Jackson, Michael Clifford. (S) *Bristol.* (I).
Johnson-Brown, Arthur. (S) *Tonyrefail.* (II).

Khan, Mohd Afzal. (S) *Rawalpindi.* (IIIa).
Koureas, Varnavas Demetri. (S) *London, N.W.*5. (I, II and IIIa).

Levy, Yermiyahu. (S) *London, N.*16. (IIIb).
Lovejoy, Dennis Philip. (S) *Fareham.* (II).

McArthur, James. (S) *Wokingham.* (I).
McCarthy, Kenneth John. (S) *London, W.*2. (I).
McDonald, Brendan Anthony. (S) *Dublin.* (IIIb).
Mehta, Mahendrakumar Ch. (S) *London, W.*12. (IIIa and IIIb).
Morris, Lionel Alfred Dodsworth. *Pontypridd.* (I, II and IIIa).
Murphy, Edward Colman. (S) *Blackrock, Eire.* (IIIa).

Nice, Richard Keith. (S) *Catterick.* (I and II).
Nichols, Basil Hopes. *Cramlington.* (I and II)

Oleinik, Swietoslaw. (S) *London, N.*7. (I).

Pandehis, Kyriakos Charles. (S) *London, W.*12. (I and II).
Pegler, George Henry. *Romford.* (IIIa).
Podlaski, Jan. (S) *Manchester.* (I).

Ranade, Maheshwar Trivikram. (S) *London, N.W.*3 (IIIb).
Richards, William Milner. (S) *London, N.*7. (I, II and IIIa).

Smit, Cornelis. (S) *Eindhoven.* (IIIa).
Smith, Maxwell Bendall. (S) *Bristol.* (IIIa).
Sofi-Zade, Isaac. (S) *London, N.*16. (II and IIIa).
Sood, Shir Dutt. (S) *Stanmore.* (I).
Spackman, Charles Bradwell. (S) *London, S.W.*14. (I).

Taylor, Edwin Leslie. (S) *Lincoln.* (IIIa).
Turnwald, Thomas Francis. (S) *Auckland.* (IIIa).

Wales, Sidney Alfred. (S) *Fareham.* (I).
Webb, Frederick Kenneth. *Soham.* (IIIb).

(S) denotes a registered Student.