The Journal of

THE BRITISH INSTITUTION OF RADIO ENGINEERS

FOUNDED 1925 INCORPORATED 1932

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

VOLUME 20 APRIL 1960 NUMBER 4

PETITION FOR A ROYAL CHARTER

THE more enthusiastically and energetically a man is engaged in profitable activity, the less easy is it for him to stand aside and make a critical and objective appraisal of his whole work.

What is true of the individual is often true of a corporate body. No Institution should, however, be so preoccupied with day-to-day work that it cannot find time for stock taking and long-term planning. In its energetic organization of new activities, in its enthusiastic planning for the future and its resoluteness in the face of difficulties, a professional institution *must* find time for systematic self-criticism—including a painstaking review of the justification for its existence or for the form in which it exists.

The decision to petition Her Majesty to grant our own Institution a Charter of Incorporation has provided the occasion for such a review. The decision has not been lightly made. A special sub-committee, consisting of the President, Past Presidents and Vice Presidents, has undertaken the task of critical review and has emerged from the undertaking with sufficient material to form the basis of a History of the Institution. This account of the Institution's history will be made available to members within the next few months.

Radio engineering has certainly developed considerably in the Institution's lifetime. Advances in technical education, new discoveries and techniques are amply demonstrated in the proceedings of the Institution over the last 35 years. As with all historical works there is a glimpse of opportunities not taken, for obvious and not so obvious reasons, and of anticipation of events; a regret that at times more positive action was not taken to influence the immediate future. In all, the history gives much satisfaction—tempered with caution in being wise after the event!

What is more important, however, is that the Institution will emerge from the process of self-examination fortified in the resolve to advance the science of radio and electronics.

Evidence has never been lacking of the desire of the membership for a Royal Charter of Incorporation. Indeed, there are members who, because of their undoubted faith in the future of the Institution and their enthusiasm for a Charter, have been impatient of the Council's caution and deliberation in this matter. The opportunity to express this enthusiasm, formally and collectively, is now provided by the Extraordinary General Meeting to be held on 28th April next, notice of which has already been sent to all corporate members. Although only corporate members may vote, members of all classes will be especially welcome at this important meeting.

The membership is well served by many active Officers whose enterprise and efforts on behalf of the Institution are so well supported by an equally active Council, and the continuing help of no less than six Past Presidents. The Institution is proud that the latter will add their signatures to those of the President and Vice Presidents as Petitioners to the prayer that in its thirty-fifth year the Institution may be granted the honour of Incorporation under a Royal Charter.

G. D. C.

EXTRAORDINARY GENERAL MEETING

NOTICE IS HEREBY GIVEN that an Extraordinary General Meeting of the corporate members (Honorary Members, Members and Associate Members) of the Institution will be held at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1, on Thursday, 28th April, 1960, at 6 p.m., for the purpose of considering and if thought fit passing with or without amendment the following resolution :—

RESOLUTION

That upon a consideration of the great development in recent years of Radio and Electronics as an independent science and with a view to advancing still further the science of Radio and Electronics and the engineering application thereof and maintaining in the interests of the public the highest possible standard of professional ability and conduct among Radio and Electronics Engineers the Council of the Institution be and they are hereby authorised to petition Her Majesty in Council for the honour of a grant of a Royal Charter incorporating the members of the Institution under the title of "The British Institution of Radio Engineers" or under such other title as to Her Majesty may seem fit for the purpose of promoting the advancement of the science and practice of Radio and Electronic Engineering and with such further objects, powers and privileges as the Council of the Institution shall think appropriate, and for that purpose to take all necessary and proper steps.

By Order of the Council.

GRAHAM D. CLIFFORD,

General Secretary.

1st April, 1960.
9 Bedford Square,
London, W.C.1.

A copy of this notice has already been sent to all corporate members together with a form of proxy. Members who are unable to attend the meeting are especially invited to complete the form and return it to the Institution not later than Tuesday, 26th April. The person appointed to act as proxy must be a corporate member of the Institution, and the President or the General Secretary will be pleased to act in this capacity.

INSTITUTION NOTICES

New Institution Premiums

The Council takes great pleasure in announcing the endowment by industrial organizations of two Institution Premiums to be awarded for outstanding papers published in the Institution's *Journal*. Premiums will be awarded annually and papers published during 1960 and falling within the appropriate terms of reference will be considered for these awards.

The first premium is to be awarded for the outstanding paper on advances in the technique of Television Broadcasting and will be known as the *Associated-Rediffusion Premium*. Its value will be £50.

Medical Electronics is the subject for which the second premium will be awarded, and this is to be known as the *J. Langham Thompson Premium*. Its value will be 30 guineas.

The generous endowment of these two new Premiums brings the total of Brit.I.R.E. Premiums and Awards up to 15. The Council has authorized the preparation of a poster giving full details of all these and members who are able to display one or more copies are invited to write to the Secretary.

Symposium on "Stable Frequency Generators"

A Symposium of seven papers on the subject of "Stable Frequency Generation" will be held in London on Wednesday, 25th May. The papers to be presented are listed under "Forthcoming Institution Meetings" in this issue of the *Journal*, and abstracts will be available on application to the Institution after 1st May. The meeting will start at 3 p.m. and consist of two sessions lasting until approximately 8 o'clock; members are asked particularly to note that this meeting will be held in the Gustav Tuck Theatre of University College, London, Gower Street, W.C.1, and *not* at the London School of Hygiene and Tropical Medicine.

Circulation of the Journal

The latest certificate issued by the Audit Bureau of Circulations shows that for the period July-December 1959, the average circulation of the *Journal* was 7,160. This does not, of course, include sales of back numbers during this period.

Education Discussion Meeting

A meeting has been arranged by the Education Committee for the discussion of its report on "The Education and Training of the Professional Radio and Electronics Engineer." This will take place on Thursday, 28th April, at 6.30 p.m., immediately following an Extraordinary General Meeting of the Institution. Accommodation will be limited, and members who wish to attend are asked to notify the Education Officer of the Institution as soon as possible; those who intend to be present may obtain a copy of the report on application.

The 1960 List of Members

All Corporate Members, Companions, Associates and Graduates have been sent free of charge their copies of the 8th issue of the *List of Members* of the Institution. Registered students, whose names are *not* included in the List, may obtain copies from the Institution, price 5s. each. To facilitate despatch, Students are requested to complete the special order forms which have been circulated with previous issues of the *Journal*.

The Institution's Calligrapher

Members will be interested to learn that Mr. H. J. Fisher of London has been commissioned to prepare the marriage certificate of H.R.H. Princess Margaret.

For nearly twenty years Mr. Fisher has engraved the Institution's certificates of membership; his craftsmanship has been particularly evident in the preparation of illuminated scrolls for Honorary Members of the Institution, and other addresses which the Institution has presented over the last fifteen years.

Acknowledgment

The paper "High Transconductance Wideband Cathode Ray Gun" by Dr. Eros Atti, which appeared in the March issue of the *Journal*, was first presented on 25th March 1958, in the Beam and Display Tubes Session of the 1958 I.R.E. National Convention held in New York. It was published in Vol. 6, Part 3 (Electron Devices) of the 1958 *I.R.E. National Convention Record*, and was reprinted by the kind permission of the Institute of Radio Engineers.

APPLICANTS FOR ELECTION AND TRANSFER

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

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

Direct Election to Member

HAROUN, Saad Allah. *Cairo.*

Transfer from Associate Member to Member

CRAWFORD, Alan Edgar. *Barton-on-Sea, Hants.*
KHARBANDA, Sant Raj Ram. *Harston, Cambs.*

Direct Election to Associate Member

BRADFORD, William Clarke. *Kilbarchan, Renfrewshire.*
GERRARD, Charles Peter. *London, N.W.3.*
MacKELLAR, John Campbell. *East Grinstead, Sussex.*

Transfer from Graduate to Associate Member

BANNOCK, Keith. *Sunbury-on-Thames, Middlesex.*
BROADBERRY, Noel Edward. *Southampton.*
BURGESS, Thomas George. *Stevenage, Herts.*
DIGBY, Peter William. *Harrow, Middlesex.*
HATHAWAY, Raymond William. *Sunbury-on-Thames.*
TAYLOR, Flt. Lt. Stanley Alfred Robert, R.A.F. *Chippenham, Wilts.*
WALSH, Michael William. *Cambridge.*
WEATHERILL, Flt. Lt. Louis, R.A.F. *Saffron Walden, Essex.*

Transfer from Student to Associate Member

ADAMS, Terrance George Frederick, B.Sc. *Ruislip, Middlesex.*
CHEUNG SHIU HUNG. *Hong Kong.*
MURPHY, Matthew. *Tallaght, Eire.*

Direct Election to Associate

BENNETT, Walter Ernest. *Wolverhampton, Staffs.*
BOOTE, Samuel Francis. *Wallasey, Cheshire.*
DICK, David, D.I.C. *Dundee.*
DICKINSON, Clifford Ivor. *Suva, Fiji.*
*McLELLAN, William Robert McRobert. *Ottawa.*
RAMSHALL, John Denis. *Knaresborough, Yorks.*
ROBINSON, George Alexander. *Sidcup, Kent.*
WADLOW, David Edward. *Knebworth, Herts.*
WATKINS, Ronald Jeffrey. *King's Lynn, Norfolk.*

Transfer from Student to Associate

WALLACE, Jack Thirlwall Frank. *Bedfont, Middlesex.*

Direct Election to Graduate

DABSON, Alec Edward. *Stevenage, Herts.*
EAST, George Frederick. *Feltham, Middlesex.*
FOOTE, Graham John. *London, S.E.3.*
HANKINS, Flt. Lt. Antony John, B.Sc., R.A.F. *King's Lynn.*
LEWIS, Brian George. *Hitchin, Herts.*
LOCK, Colin Sidney. *Chelmsford, Essex.*
NAPPIN, Donald, B.Sc. *South Harrow, Middlesex.*
THIRKELL, David. *Dunstable, Bedfordshire.*

Transfer from Student to Graduate

BOWEN, Joseph Alfred Edward. *Crawley, Sussex.*
COLLINS, Brian. *St. Albans, Herts.*
HENDERSON, Douglas Ross. *Codsall, Staffs.*
KEMP, Paul Courtney. *Plymouth, Devon.*
KERVELL, Michael George. *Cambridge.*
PANCHAPAKESAN, Ramachandra, B.Sc. *Madras.*
RUBEN, Moshe. *Kiryat Yam, Israel.*

STUDENTSHIP REGISTRATIONS

The following 83 students were registered at the February and March meetings of the Committee.

ABOUL-SEOUD, Ragaa, B.Sc. *Cairo.*
AGBANA, Elisha. *Egbe, Nigeria.*
BHAKAR, Amar Singh. *Bombay.*
BRENDISH, Stewart. *Wembley Hill, Middlesex.*
CHAMBERS, Alfred Joseph. *London, N.15.*
DARSHAN SINGH. *India.*
DU BARRY, James. *Deenlaoghaire, Co. Dublin.*
EDET, Arthur Antigha. *Lagos, Nigeria.*
EVANS, John Hadley. *Sheffield 11.*
GLOVER, Geoffrey. *Stoke-on-Trent, Staffs.*
HIRSCHHORN, Haim. *Haifa, Israel.*
JOHNSTONE, Michael. *London, N.W.6.*
KACZKA, Gordon, B.Sc. *Manchester.*
KWAPNIEWSKI, Jerzy J. *London, W.11.*
LEE HIN-CHUNG. *Hong Kong.*
LIM JIN TWAN. *Rangoon, Burma.*
NATH, Pulin Chandra. *London, N.19.*
OSBORNE, Peter David. *London, N.W.7.*
PERRY, John F. *Marlborough, Wiltshire.*
POVALL, Alan. *Lytham St. Annes, Lancs.*
REED, Donald David. *Bedford.*
SIMMONDS, Donald. *Totton, Hampshire*
SMITH, Colin. *Whitchurch, Cardiff.*
TAKKAR Sushil Kumar. *Cochin, India.*
TAYLOR, Eric Victor. *Ilford, Essex.*
TOWNSEND, James H. *The Hague.*
TAYLOR, Harold. *Old Woking, Surrey.*
TURNER, Derek. *Spalding, Lincs.*
WADDINGTON, Bryan. *Farnham, Surrey.*
WHELAN, Nicholas K. *London, S.E.24.*
WILLIS, Roy. *Totton, Hampshire.*
WINTLE, John. *Waihi, New Zealand.*
YONG, Phang Chong. *London, W.1.*

ASHFIELD, John E. *Rickmansworth, Herts.*
*AYIVORH, Samuel Clifford. *Kumasi, Ghana.*
BENNETT, Malcolm. *Dartford, Kent.*
BLOXHAM, Derek J. *High Wycombe, Bucks.*
BOYCE, Allan Harry. *Reading, Berks.*
BRAHAM, Brenda. *London, E.5.*
BURGESS, Gordon S. *Fareham, Hampshire.*
BUNCE, Neville Randolph. *B.F.P.O. 43.*
CHAMBERLAIN, Brian G. *Wellington.*
CHAN, Kum Yan. *Singapore.*
CHICK, Alan. *Coventry.*
COIA, Ferdinando, B.Sc. *Glasgow.*
CORY, Frederick John. *Plymouth, Devon.*
CRAMP, Donald Henry. *Mitcham, Surrey.*
CROMIE, David James F. *Kilkeel, N. Ireland.*
ELLIOTT, Brian Charles. *Reading, Berks.*
EVANS, Keith Michael. *Salisbury, Wilts.*
GAZMURI-SYMMES, Carlos. *Cambridge.*
GHALLEY, Jaspal Singh. *London, S.E.27.*
GIBBONS, Geoffrey F. *Southampton.*
GIBBY, Leslie Ernest. *Cardiff.*
HADDAD, Tewfik. *London, N.4.*
HAIZEL, Kwamina Bainyi. *London, W.9.*
HENDY, Jeffrey Alan J. *Southampton.*
HOWARD, Patrick J. *Clevedon, Somerset.*
HURSEY, Donald D. *London, W.6.*

JAYATUNGE, Nihal Gamini. *Brighton.*
JONES, Peter. *Romford, Essex.*
KNOX, Raymond L. *North Wembley, Middlesex.*
LEWIS, Carey. *Abingdon, Berkshire.*
LYE, Khay Fong. *Singapore.*
MALIK, Mohammad Riaz. *Leeds.*
*MATHUR, Sushil Kumar. *Jodhpur.*
MAY, David Harold. *Plymouth.*
NORTON, Martin A. *Harrow, Middlesex.*
O'RIORDAN, William. *Brentwood, Essex.*
ORBELL, Arthur George. *Cambridge.*
PEARCE, Roger Frederick. *Bristol.*
PETTINGER, John Ernest. *Solihull, Warks.*
PURANIK, Shreeram, M.Sc., B.Sc. *Bombay.*
QUINNEY, Ronald E. *Reading, Berkshire.*
RATNAJOTHI, Navaratnam. *Colombo.*
ROBINSON, Brian Arthur. *Harrogate.*
SAMUEL, Stephen Dharmarajah. *London, W.14.*
SIDDIQI, Wasi Ahmad. *Sidcup, Kent.*
*SINGLA, Ratanial. *New Delhi.*
STOKES, John F. A. *Wembley, Middlesex.*
TURNBULL, Herbert J. *Bishop Auckland, Co. Durham.*
UKO, Okon Nathaniel. *Lagos.*
WALKER, Gordon Henry. *Glasgow, W.3.*

* denotes a reinstatement.

Some Recent Improvements in Low Power Pulse Generators†

by

R. P. F. LAUDER, B.SC., ASSOCIATE MEMBER‡ and P. A. JAMES, B.SC.‡

Summary: Three low power pulse generators used as sub-modulators driving a 5C22 type of thyratron are described. These may be triggered by an external sine wave or pulse source, or may free-run with a high degree of temperature stability. All circuits use miniature thyratrons. A circuit showing a method of overcoming the limitation of maximum duty ratio of the 2D21 is also presented.

1. Introduction

The sub-modulator is generally the heart of any radar system, the prime mover where the repetitive process of transmitting pulsed information is initiated. It either generates the fundamental pulse recurrence frequency (p.r.f.) or accepts some repetitive waveform generated elsewhere and converts it into a form suitable for presentation to the main modulator as a trigger. It often performs subsidiary functions such as the production of other lower powered pulses, generally earlier in time than its main output pulse, for use as triggers. For example few oscilloscopes present a true picture of the leading edge of a pulse when the pulse itself is used to trigger the time-base circuits, and even fewer oscilloscopes are capable of having their free-running fast time-bases synchronized so that the leading edge of a pulse may be viewed somewhere reasonably near the centre of the time-base without jitter. In short, even the best oscilloscopes have to be jogged into activity a few microseconds before they are asked to present the best representation of a narrow pulse of which they are capable. Three circuits will be described, all of them being capable of either being triggered from an external source, or of generating the fundamental p.r.f. by free-running.

2. Requirements of the Two Systems

2.1. *The Triggered Circuit*

The triggered version of the circuit has the following specification:

Input trigger:	3kc/s sine wave 28V peak-to-peak amplitude from a high impedance source (about 100kΩ).
Output (1)	A positive-going pulse 1·5 to 2·0μsec wide, 0–30V peak amplitude at a p.r.f. of 1000 pulses/sec occurring at time $T = 0$.
Output (2)	A positive-going pulse of 15V minimum amplitude, at a p.r.f. of 1000 pulses/sec (shape unspecified, but to have a leading edge of not more than 0·1μsec) to be used as an oscilloscope trigger. Occurring at time $T=4$μsec.
Output (3)	A positive-going pulse 3·5 to 4·0μsec wide of 200V to 250V amplitude at a p.r.f. of 1000 pulses/sec. Occurring at time $T = 5$μsec. For use as a trigger to the main modulator, and feeding into 437Ω impedance.

The available supplies are +250V h.t., −150V bias and 200V 400 c/s mains (for heaters). A further requirement is that the circuit should "fail safe" in the absence of h.t., bias, and/or input trigger.

2.2. *The Free-running Circuit*

The free-running version is required to generate a p.r.f. of 315 ± 5 pulses/sec with provision for fine adjustment of the p.r.f. as a pre-set control. The three outputs are the same as in Sect. 2.1 except for the difference in p.r.f.

Both units are required to fit on to a small chassis of an uncompromisingly triangular shape, withstand the usual climatic and vibration conditions common to modern service equipment and, further, to work with an

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‡ Ferranti Ltd., Edinburgh.

U.D.C. No. 621.373.44

additional environmental hazard in the form of a strong magnetic field due to the close proximity of the magnetron in the main modulator.

2.3. *Consideration of the Factors affecting the Basic Design*

It will be noticed from the list of requirements in Sect. 2.1 that all the outputs are at the same p.r.f., but that this p.r.f. differs by a factor of three from the input. Therefore the circuit must "count down" by this amount. Further, it is not sufficient to generate a pulse and then successively delay it up to 5 microsec and use it as the final output since the required pulses vary in width, and pulse width clipping is not an easy process. It was decided therefore, that two stages would be required and the basic block diagram is shown in Fig. 1.

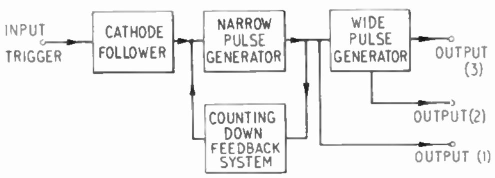

Fig. 1. Block diagram of the basic circuit.

Since the input trigger comes from a relatively high impedance source, a cathode follower is inserted into the input lead.

3. First Design

3.1. *Basic Pulse Generation*

Both stages of the sub-modulator use the method of pulse generation common to many high power modulators, i.e. charging up the capacitors of a pulse-forming network by means of a resonant charging system, and then discharging the network at the appropriate instant into a matched load via a switching valve. Figure 2 shows the arrangement..

L is the charging reactance which isolates the power supply from the load R_L when the switching valve S1 conducts. The pulse forming network (PN) is represented by its total capacitance C_N and has its surge impedance equal to R_L.

Neglecting losses, after a time t equal to twice the "one way" discharge time of PN, the point A will be at earth potential and will return resonantly to a voltage equal to twice the h.t. voltage, in a time T given by

$$T = \pi\sqrt{LC_N} \qquad \text{.........(1)}$$

Switch S2 is unnecessary if T can be made equal to the time interval between pulses, but is required in other circumstances, and in this case, represents a "hold-off" diode.

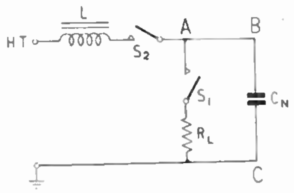

Fig. 2. Basic charging circuit.

Extra discharge networks with their loads may be connected in parallel with terminals B and C, provided eqn. (1) is not violated, and provided that extra hold-off diodes are used to prevent any stage from discharging pulse forming networks other than its own.

3.2. *Choice of Switching Valves*

The output pulse is some 250V in amplitude feeding into an external impedance of 437 ohms, the output current pulse required is just over 0·5 A. The pulse forming networks have to be kept to a reasonably low impedance and at the same time, fulfil the requirements of eqn. (1). The h.t. supply is +250V, and with a resonant charging system, may rise to approximately +500V. We therefore require a switching valve which is physically small; is capable of holding off at least 500V on its anode; has the minimum voltage drop when it is conducting; is capable of passing at least 1·5 to 2A peak anode current; and for a pulse whose leading edge is to be of the order of 0·1 microsec, must deal with rates of change of current of the order of 15 to 20 amps per microsecond. Since a bias supply of −150V is available, a positive grid control characteristic is not essential.

These conditions are fulfilled in the 2D21 valve which has the characteristics shown in Table 1. It has a negative grid characteristic and thus requires a negative bias to be applied to the grids between pulses. The two grids are both control grids and may each be used as

Table 1

Characteristics of 2D21 Thyratron

Peak forward anode volts 500V			
Peak anode inverse volts 100V			
D.c. grid volts:	grid 1	−10V	Conducting
	grid 2	−10V	
Pulse grid volts:	grid 1	−100V	Non-conducting
	grid 2	−50V	
Heater—cathode volts			
Peak cathode current			
Mean cathode current			
Peak grid currents:	grid 1	20mA	
	grid 2	20mA	
Rate of rise of cathode current 100A/μsec.			
Heater supply 6·3V at 0·6A			
Dimensions: 1¾ in. overall seated height.			
¾ in. diameter.			
Base: B7G.			

such. The only difference between them is the maximum negative pulse which may be applied in the non-conducting state.

This small thyratron was chosen for each of the two switching stages.

3.3. *The Feedback "Count-down" Circuit*

The function of the feedback circuit is to cause the first stage to conduct only on each third cycle of the trigger waveform by biasing off the thyratron for a period slightly shorter than 1 millisec (the interval between output pulse). Basically the circuit is a form of pulse stretcher. Consider the action of Fig. 3 when supplied with a negative pulse.

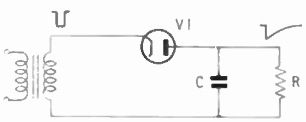

Fig. 3. Basic pulse-stretching circuit.

The capacitor C is charged almost to the peak value of the pulse through V1. The diode is thus left with its anode at a potential considerably more negative than its cathode and is thus cut off. The capacitor then discharges through the resistor R in a time dependent on the product *CR* giving the exponential waveform shown.

The circuit of Fig. 4 is basically the same as that of Fig. 3 although the components have been rearranged.

If the point A is connected to the grid of the thyratron, the pulse appearing on the secondary winding of the transformer will charge capacitor C to a negative potential. The thyratron and V1 are both cut off, and the potential on C will start to rise exponentially towards h.t. with a time-constant equal to *CR*. However, when this potential reaches the firing potential of the thyratron grid, the waveform will be held at this point by grid current.

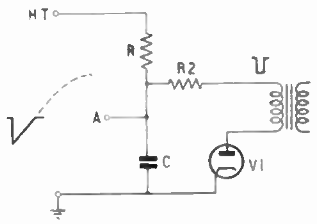

Fig. 4. Actual feedback circuit.

It will be noticed in passing, that the point A is held at a slight positive potential in the absence of a trigger, due to the flow of current through R1 and R2, the winding of the transformer and V1. R2 is included to limit the pulse current flowing into the capacitor to the permissible safe level for V1.

The point A in Fig. 4 is connected to grid 1 of the thyratron since it will be noticed in Sect. 3.2 that this grid may assume a maximum negative voltage of −100V in the non-conducting state, compared with −50V on grid 2. This allows the *CR* circuit to have a lower value of *CR* due to the higher voltage available.

Once the main discharge between anode and cathode of a gas-filled valve has been initiated, lowering the grid voltage will have no effect on the anode current. Thus the voltage generated at point A does not in fact cut off the valve, but merely holds it off once the discharge has ceased due to the anode voltage dropping to a very low value (about 10V).

The values of *C* and *R* are not very critical in the triggered version of the circuit since it will be appreciated that the feedback waveform must *not* have recovered by the time the second input trigger arrives, but must have fully recovered before the third. Since these two intervals are separated by 333 microsec, the precise recovery period is clearly not critical.

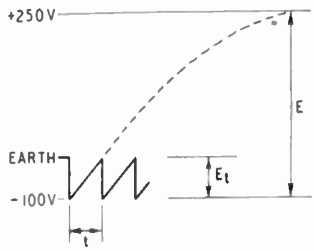

Fig. 5. Feedback waveform.

The component values may be estimated as follows. Consider the feedback waveform as shown in Fig. 5.

The capacitor is charging *towards* $+250$V although it is "caught" at earth potential by the thyratron grid. Therefore its shape is defined by the product CR and the total applied voltage 250V + 100V(E). The time interval of interest (t) is the time taken for the capacitor to charge from -100V to earth potential (E_t). The equation then is:

$$E_t = E\,[1 - \exp\,(-t/CR)] \qquad \text{.........(2)}$$

$$CR = \frac{t}{\log_e\left(\dfrac{E}{E - E_t}\right)} \qquad \text{.........(3)}$$

Substituting the values shown in Fig. 5, and putting $t = 10^{-3}$ sec, we find the value of $CR = 2{\cdot}94 \times 10^{-3}$ sec.

This is the maximum permissible value of CR to ensure division of the input frequency by a factor of 3. A larger value of CR will result in division by 4. The smallest permissible value is given by putting $t = \frac{2}{3} \times 10^{-3}$ sec in eqn. (3), and this gives a value of $CR = 1{\cdot}96 \times 10^{-3}$ sec. A smaller value would result in division by 2. The mean of these two limits is $2{\cdot}45 \times 10^{-3}$ sec and this may be given the tolerance $\pm 0{\cdot}49 \times 10^{-3}$ sec.

Taking standard values of C and R, we may arrive at a reasonable compromise with

$$C = 3{,}300 \text{ pF}$$
$$R = 680 \text{ k}\Omega$$
$$\text{giving } CR = 2{\cdot}24 \times 10^{-3} \text{ sec.}$$

The effects of temperature on this circuit are considered later in Sect. 3·8.

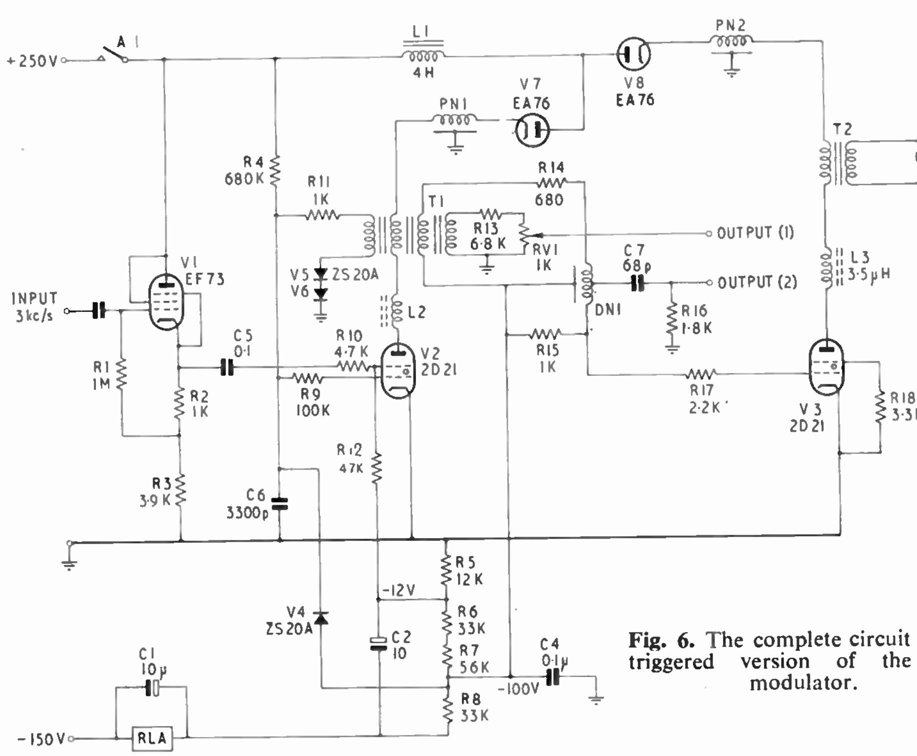

Fig. 6. The complete circuit of the triggered version of the sub-modulator.

This calculation is to some extent approximate due to the de-ionization currents flowing in the grid circuit affecting the start of the discharge waveform in a highly non-linear and unpredictable manner.

The requirement in the valve specification that grid 1 shall not assume a more negative voltage than -100V in the non-conducting state imposes a restriction on the voltage E_t in eqn. (3). To overcome this difficulty, the voltage on grid 1 is limited by a silicon diode connected to a -100V tap on the bias chain.

The complete circuit is now shown in Fig. 6 PN1 is a 1·75 microsec pulse forming network of 175 ohms impedance and PN2 is a 3·9 microsec pulse forming network of 193 ohms impedance. The load for PN1 is the total combined impedance of the three secondary windings of T1, and that of PN2, the reflected impedance in the primary winding of T2.

Impedance considerations in the first stage will now be discussed. Denoting the three secondary windings of T1 by S1, S2 and S3, and the turns ratios of each with respect to the primary by n_1, n_2 and n_3; then the reflected impedance in the primary winding will be the parallel combination of the three impedances:

$$\frac{Z_{S1}}{(n_1)^2},\ \frac{Z_{S2}}{(n_2)^2},\ \text{and}\ \frac{Z_{S3}}{(n_3)^2}$$

Figure 7 shows the anode circuit of V2 in more detail, including the number of turns in each winding. The circuit in the S1 winding is non-linear and it is necessary to calculate the impedance at the leading and trailing edges of the pulse separately. At the start of the pulse, the capacitor is uncharged and may be regarded as a short circuit. The forward impedance of the silicon diode is very low compared with the 1 kilohm resistor and will be neglected. Thus at the start of the pulse, the only significant impedance in the S1 winding is the 1-kilohm resistor.

In the S2 winding, the delay network PN1 has a characteristic impedance of 1 kilohm and is matched at its output end. When the grid-cathode space in V3 is ionized by the drive pulse, the 2·2-kilohms grid resistor is connected in shunt with the 1-kilohm matching resistor. However this happens 5 microsec after the time considered here and does not affect the impedance in S2 when V3 is cut-off. Therefore the total impedance in S2 is 1·68 kiloms. The impedance in S3 is purely resistive, and is 7·8 kilohms in value.

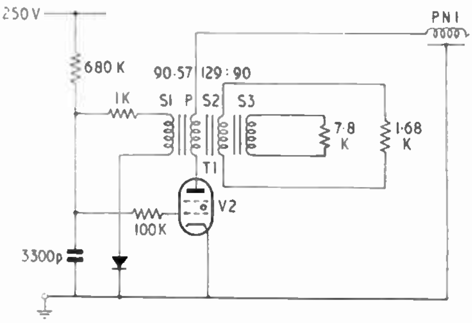

Fig. 7. The anode circuit of V2.

Thus at the start of the pulse, the reflected impedance in the primary winding of T1 is the parallel combination of the following three impedances

$$10^3 \times \left(\frac{57}{90}\right)^2 = 400\Omega$$

$$1{\cdot}68 \times 10^3 \times \left(\frac{57}{129}\right)^2 = 329\Omega$$

$$\text{and}\quad 7{\cdot}8 \times 10^3 \times \left(\frac{57}{90}\right)^2 = 3120\Omega$$

This results in an impedance of 171 ohms which is a reasonable match for the 175-ohms impedance of PN1.

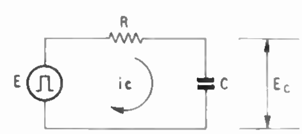

Fig. 8. Equivalent feedback circuit at the end of the pulse.

At the end of the pulse, the reflected impedances of S2 and S3 remain unchanged at 329 ohms and 3120 ohms respectively but the impedance of S1 must be re-examined. This is most easily understood by reference to Fig. 8 which shows the essential parts of the circuit. We will write down the equations for the voltage across, and the current through, the capacitor and solve for the impedance of the capacitor at the time t equal to the pulse width.

These are

$$E_c = E[1 - \exp(-t/CR)] \quad \text{.........(4)}$$

$$i_c = \frac{E}{R}\left[\exp(-t/CR)\right] \quad \text{.........(5)}$$

whence

$$Z_c = \frac{E}{i_c} = R\left[\exp(t/CR) - 1\right] \quad \text{.........(6)}$$

In this case $R = 10^3$, $t = 1{\cdot}75 \times 10^{-6}$, and $C = 33{\cdot}3 \times 10^{-9}$.

whence $Z_c = 699\Omega$ at time t.

This is the impedance of the capacitor alone. The diode is still conducting, thus its forward impedance may be neglected, but the impedance of the resistor R must be added to this to obtain the total impedance in S1 of $1{\cdot}699 \times 10^3$ ohms. Reflecting this impedance into the primary circuit as before gives a value of 680 ohms and the total primary impedance is 206 ohms which is a rather poorer match for the 175-ohms pulse-forming network, so that we may expect the trailing edge of the output pulse to be slightly degraded. This in fact does happen, but to a relatively trivial extent.

It may be argued that the 6·8 kilohms resistor in S3 and the 680-ohms resistor in S2 are unnecessary since the reflected impedances of these two circuits could have been corrected by adjusting the turns ratio of T1. This argument is of course valid but the transformer used is a standard item readily available and was therefore used for that reason.

3.4. *Biasing Arrangements*

Examination of Fig. 6 makes it clear that since grid 1 of V2 is at a slight positive potential, grid 2 must be biased to prevent V2 from conducting in the absence of a trigger. The coil of relay RLA has a d.c. resistance of 14 kilohms, thus the bias chain passes approximately 1mA and the bias applied to grid 2 of V2 is therefore about −12V. The output of the cathode follower stage is a sine wave of 28V peak to peak amplitude and therefore has its axis of symmetry at −12V with respect to earth. Thus grid 2 of V2 is driven 2 volts positive on each cycle and the valve conducts on every third cycle. Figure 9 showing the waveforms on the two grids, makes this clear.

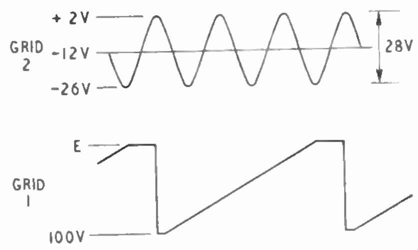

Fig. 9. Trigger and feedback waveforms.

The anode of the silicon diode V4 is connected to the −100V point on the bias chain. V4 conducts when the voltage in the feedback network goes more negative than this value, thus the waveform on grid 1, is limited to −100V. The −100V line is also connected to grid 1 of V3 via S2 of T1. Grid 2 is not required in this version of the circuit and it is therefore connected to cathode via a 3·3 kilohms resistor.

3.5. *The Output Stage*

Output (1) referred to in Sect. 2.1 is taken from the tap on the 1-kilohm potentiometer in the S3 winding of T1 and may be adjusted to any amplitude within the 0–30V range.

The pulse occurring in the S2 winding is taken to the grid 1 of the output stage V3 via a 5 microsec delay line DN1. A tap on this delay line 4 microsec from the input end provides the output (2) used as a trigger. Since DN1 is at −100V level in the absence of a pulse, it was considered undesirable to take this point out directly because of the danger of shorting out the second stage bias. Since a blocking capacitor was the obvious solution, the opportunity of improving the rise-time and shortening the pulse was taken by introducing a differentiating circuit into this lead. It is also useful in minimizing the effects of shunting the relatively low input impedance of the trigger circuit of many oscilloscopes across this output. It was considered unnecessary to remove the resulting negative part of the pulse.

The drive from the output of DN1 is about 250V amplitude with its base line at −100V, thus it drives the grid of V3 about 150V positive. V3 fires and discharges PN2 through the reflected impedance of the output of T2. The impedance of the grid circuit of the 5C22 type thyratron in the main modulator is 437 ohms. The step up ratio of T2 is 1.5:1 ; thus the reflected impedance in the primary is $437/(1{\cdot}5)^2 = 194$ ohms which matches the 193-ohms impedance of PN2.

3.6. *The Pulse-forming Networks*

The two pulse-forming networks and the delay network are all contained within one rectangular resin casting, approximately 3 in. × 2 in. × $\frac{7}{8}$ in.

PN1 is an L-section line of 5 sections having a delay of 0·175 microsec/section and a total capacitance of 5000 pF with an impedance of 175 ohms. PN2 is also L-section with 5 sections, a delay of 0·290 microsec/section, impedance of 193 ohms and total capacitance of 7,500 pF. Thus the total capacitance charged up by the charging circuit is 12,500 pF; the charging choke is 4 henries, hence T from eqn. (1) is 0·702 millisec which is 30 per cent. less than the time interval between pulses.

The delay line is 20 sections of 1 kilohm impedance and 0·27 microsec delay/section. In order to accommodate this line within the physical dimensions of the resin casting it is necessary to wind it on two separate formers. All the capacitors are 270 pF with the exception of the end capacitors at the joint of the two formers. At this point they are 150 pF at the end of one former, and 120 pF at the start of the next. They are connected effectively in parallel. This arrangement gives a better response than the method of terminating one former in a 270 pF capacitor and starting the next former with an inductance.

3.7. *Other Features*

Another requirement listed in Sect. 2.1 was that the circuit should "fail-safe" in the absence of h.t., bias and/or input trigger. This has been accomplished as follows. Should the input trigger fail for any reason, grid 1 of V2 will recover to earth potential as indicated in Fig. 9, but grid 2 will assume a steady bias of −12V which is sufficient to prevent conduction in V2. Similarly grid 1 of V3 is biased to −100V and cannot conduct under these circumstances. If the +250V line should fail, conduction is impossible in any of the valves. If the −150V line should fail, current ceases in the bias chain and relay RLA is de-energized, contacts A1 open, thus removing the +250V supply and again conduction is impossible. Thus the circuit "fails-safe" under any of these circumstances assuming that it has already been working in a normal manner.

Under the transient conditions obtaining on first switching on however, a rather different set of circumstances prevails. The 2D21 thyratron is capable of conduction at very low anode voltages (of the order of 10V). Thus if the h.t. supply should appear in the circuit, a very short time before the bias supply, the valves may fire, and thereafter the biasing arrangements are powerless to prevent continuous conduction.

It is desirable therefore, that the supplies should arrive at the circuit in the order–bias, h.t., trigger. This system has been obtained by the following device. A 10-μF capacitor (C1) is connected in parallel with the coil of the relay, thus imparting a time delay to the action of the relay and hence to the application of h.t. A second 10-μF capacitor (C2) is connected between the −12V bias line and the −136V line (see Fig. 6). Thus the −12V line is held to −136V until C2 has charged up through R5. This has the effect of delaying the trigger for this time.

The small 3·5-microhenries chokes in the anode circuits of the two thyratrons are included to prevent the charged-up stray capacitances associated with the anode circuits from discharging through the valves on triggering and producing spikes of current which lead to reduced life of the thyratrons.

The two hold-off diodes V7 and V8 are necessary to prevent either thyratron from discharging the pulse-forming network belonging to the other stage.

The silicon diodes used in these circuits have a maximum PIV rating of 110V, thus it is necessary to use two in series where the peak voltages exceed this figure. The EA76 type of diode has also been used in these positions where one only is sufficient, but imposes an extra load on the heater supply and takes up more room.

The proximity of the magnetron mentioned in Sect. 2.2 necessitated the "off mounting" of the relay and its associated capacitor to another part of the equipment. Although it is possible to prevent a 2D21 from firing by an external magnetic field this problem did not arise in the geography of the equipment.

3.8. *The Free-running Circuit*

In order to make the circuit of Fig. 6 generate its own p.r.f., it is only necessary to remove the cathode-follower stage and connect grid 2 of V2 to cathode via a 3·3-kilohm resistor. The CR circuit R4, C6, will then determine the p.r.f. in the manner already described.

The free-running version built is required to supply a p.r.f. of 315 pulses per second with a tolerance of ±5 pulses/sec. In this circuit, the same value of capacitor is used, namely 3,300 pF, and the total resistance is increased to 2·67 megohms. This resistance is composed of a 2-megohms resistor in series with a 1-megohm potentiometer which gives the twofold advantage of removing the selection tolerances from the circuit and giving a measure of control over the p.r.f. The removal of selection tolerances permits looser toleranced components to be used but has no effect on temperature drifts.

This effect is minimized by careful choice of components as follows. The potentiometer is a miniature carbon type RVC-12 which has a temperature coefficient of −0·12 per cent./°C. The 2-megohms resistor is a glass fibre type with a coefficient of +0·03 per cent./°C. It is easily shown that, if two resistors R1 and R2 with temperature coefficients of x_1 and x_2 are connected in series, then y, the temperature coefficient of the combination, is given by

$$y = \frac{R_1}{R_1+R_2}x_1 + \frac{R_2}{R_1+R_2}x_2 \qquad \ldots\ldots\ldots(7)$$

Assuming that the 1-megohm potentiometer is set at a resistance of 670 kilohms, the combined coefficient of the pair is −0·0076 per cent./°C.

The capacitor chosen is a polyester dielectric type which has a temperature coefficient of +0·02 per cent./°C. Assuming a 50°C rise in temperature, the combined resistors will fall by 0·4 per cent. and the capacitance will rise by 1 per cent. thus the total effect will be an increase in the value of *CR* by 0·6 per cent. and thus the p.r.f. will drop from 315 pulses/sec to just over 313 pulses/sec which is well within the stipulated tolerance.

It has been found in practice that the triggering level of the 2D21 thyratron is reasonably stable[1]. Variations in this level will of course affect the p.r.f. generated and in fact a tolerance of 315 pulses/sec ±15 pulses/sec was eventually found to be acceptable in the equipment with which this sub-modulator was associated. Variation of triggering level in the valve is difficult to calculate and impossible to control, nevertheless its effect must be taken into account when considering p.r.f. stability.

4. A Novel Form of the Sub-modulator

Referring to Fig. 10, the basic discharge circuit, where the impedance of the pulse-forming network Z_0 is matched to the load resistor R_L, a voltage pulse having half the peak charge voltage of the PN will appear across R_L when switch S is closed, due to the flow of current *i*.

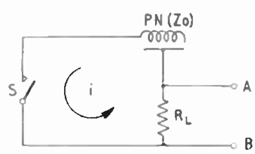

Fig. 10. Basic discharge circuit.

The polarity of the pulse will depend on the reference point from which the pulse is observed. For example, if the point A in Fig. 10 is earthed, then a positive pulse will appear at B. Conversely, if point B is earthed a negative pulse will appear at point A. Further, the components PN, S, and R_L may be arranged in any order, provided they form a closed loop.

With these points in mind, it is possible to substitute resistive loads for the transformers in Fig. 6 without any loss in performance. Considering the output stage first. We require a

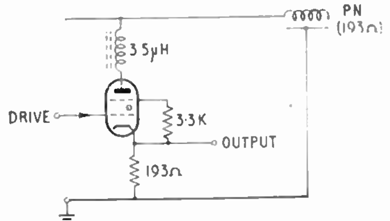

Fig. 11. Practical discharge circuit with resistive load.

positive-going pulse of 200V minimum amplitude, and one side of the output may be earthed. Neglecting losses, the peak charged voltage on the network will be 500V, allowing 10V drop across the switching valve, we are left with 240V available to appear across the load resistor. Since the impedance of the network is 193 ohms this must be the value of the load resistor to achieve a match. Figure 11 shows the arrangement. It must be noticed in passing that this circuit is *not* a cathode follower despite its appearance, since the cathode of a gas-filled valve will not follow the grid variations.

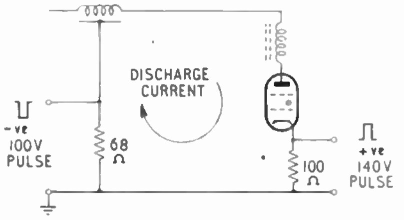

Fig. 12. Practical discharge circuit giving positive and negative pulses.

With a 240V output pulse, the peak current is clearly 1·24A. With this circuit, of course, a separate heater supply is necessary. The first stage is required to produce both the −100V feedback voltage and the grid drive to the second stage. Since the advantages of the step-up ratios of transformers have been abandoned, the maximum remaining voltage available, allowing for a 10V drop in the valve, is 140V. We now have to arrange the load for the pulse forming network so that part of it produces a −100V pulse and the remainder a +140V pulse. Figure 12 shows how this may be achieved.

Tre current in this discharge loop is 1·43A allowing a 10V valve drop. The −100V pulse is now applied to the CR stretching circuit whicr must be referred to the cathode of the 2D21, and the complete circuit now becomes that of Fig. 13 which is the free-running version. This circuit may be triggered as before by removing the 3·3-kilohms resistor from grid 2 of V1 and applying the input sine wave via the cathode follower as shown in Fig. 6. The 1-kilohm potentiometer across which the output (1) is developed is in parallel with the 100-ohms cathode resistor, hence output (1) must be fed into a reasonably high impedance otherwise both the shape and the amplitude of the drive pulse to the second stage will be impaired.

This circuit has been built and found to perform as well as the "transformer" version but with obvious economy both of space and money. One slight disadvantage of this circuit is that

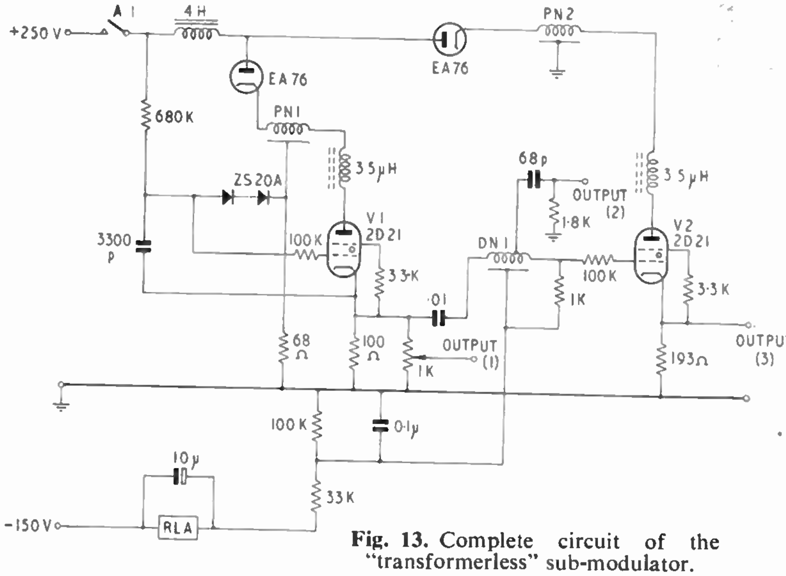

Fig. 13. Complete circuit of the "transformerless" sub-modulator.

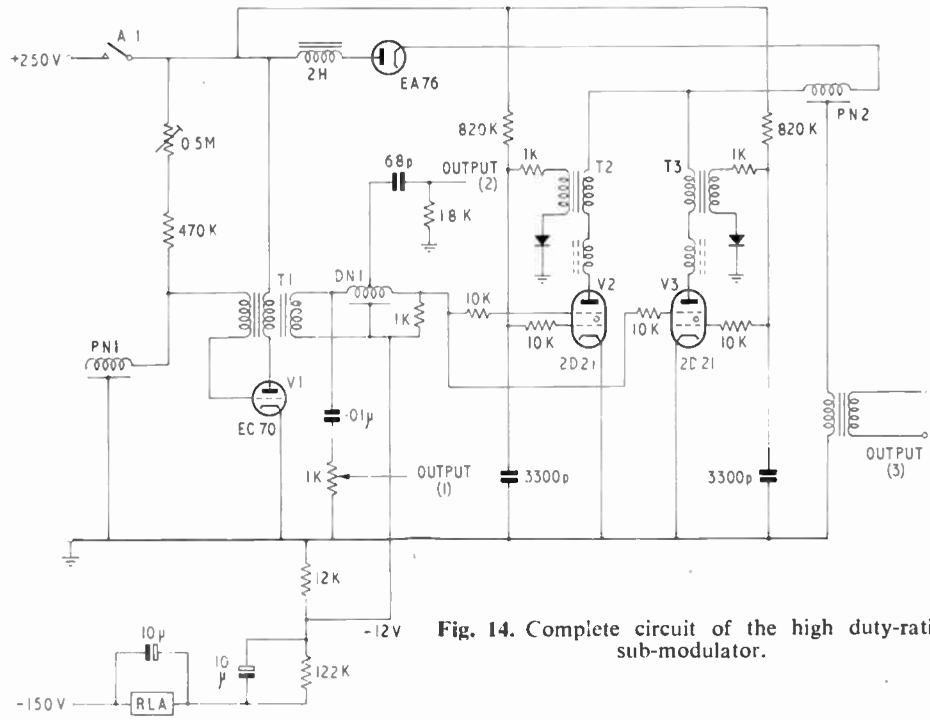

Fig. 14. Complete circuit of the high duty-ratio sub-modulator.

each valve requires a separate heater winding, although the total amount of energy for heaters naturally remains the same.

5. A Higher Duty Ratio Circuit

If a p.r.f. greater than 1000 pulses/sec is required, a fundamental difficulty is immediately met with, in that, under the present working conditions, the 2D21 valves are already operating at their maximum duty ratio consistent with reasonable life. A free-running modulator was required with precisely the same specification as that shown in Sect. 2.1, except that the p.r.f. was 2000 pulses/sec.

In this case, a hard valve pulse generator is used to provide the fundamental 2000-pulses/sec p.r.f. and two 2D21's are then triggered alternately to discharge the same pulse forming network into the same load. By this means, each gas valve is working at its maximum duty ratio at a p.r.f. of 1000 but tre output pulse is at a p.r.f. of 2000 pulses/sec. Figure 14 shows the circuit.

Here a subminiature triode is used as a straightforward blocking oscillator with its pulse width controlled by PN1, and a p.r.f. of 2000 pulses/sec. As before, the output is delayed 5 microsec by DN1 which alro carries a +12V bias line, and is applied simultaneously to tre second grids of both V2 and V3. Considering the case of first switching on, the first grids of both valves are at a slight positive potential, and the second grids are simultaneously lifted to firing voltage, therefore both valves will attempt to pass current. Due to very small differences in the valves themselves, and to their wiring one valve will predominate and pass most of the discharge current of PN2. Assume that tris valve is V2. It will then bias itself off on grid 1 due to the feedback network associated with its own anode circuit, and will remain biased off for one and a half pulse intervals, thus when the second pulse arrives at grid 2 of V2 and V3, only V3 will be in a position to pass current. At the time of arrival of the third pulse, V3 will be biased off, but grid 1 of V2 will have recovered to a slight poritive potential and so on. Figure 15 shows the waveforms at the two grids of V2 and V3, and the output pulse from T4 making this action obvious.

It will be noticed in Fig. 14 that the charging choke has been reduced from 4 henries to 2 henries. This is necessary since PN2 is being discharged successively by V2 and V3, it must recharge to approximately 500V in the period between *output* pulses, i.e. in rather less than 500 microsec compared with 1 millisec for a p.r.f. of 1000 pulses/sec.

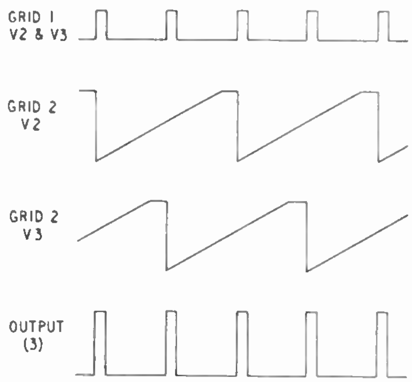

Fig. 15. Timing waveforms of the high duty ratio circuit.

This system may be extended by the addition of more stages in parallel with V2 and V3, but the limit is reached when the interpulse charging period demands that the anode voltage has to rise so rapidly that the grid does not regain control before conduction starts again. Ohmstead and Roth[1] and others[2-4] have discussed this more fully. The blocking oscillator design is unexceptional and many papers—notably that of Benjamin[5]—discuss the design.

6. Conclusions

Several versions of low power pulse circuits have been presented which give a variety of outputs of good pulse shape suitable for driving the 5C22 type of thyratron in a high power pulse transmitter. The circuits may be either driven from an external sine-wave or pulse source or may free-run with a closely-controlled p.r.f.

7. Acknowledgment

The authors thank Mr. M. Powley, manager of the Instrument and Fire Control Laboratory of Messrs. Ferranti Ltd., Edinburgh, for his permission to publish this paper.

8. References

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MEMBERS OF THE COUNCIL

Born in Ilford in 1900, **George William Raby** was educated at Oundle and received his technical training as an apprentice with British Thomson-Houston Ltd. He served in the R.A.F. towards the end of World War I, and on returning to B.T.-H. held various posts, becoming superintendent controller, factory in 1924. From 1928 to 1930 he was works manager with Richardsons Westgarth-Brown Boveri; he then joined the English Electric Company at Rugby, subsequently becoming assistant general manager.

At the outbreak of war Col. Raby went overseas with the B.E.F.; on returning to England he was appointed superintending engineer at the Air Defence Research and Development Establishment working with Sir John Cockcroft on the development of radar devices. In 1944 Colonel Raby became chief superintendent of the Signals Research and Development Establishment, a position he held until 1947. He was appointed a C.B.E. in 1946.

Colonel Raby then took up an industrial appointment in South Africa, and was later, for four years, chairman and managing director of the Sudan Gezira Board. He entered the nuclear engineering field in 1956 as deputy director (engineering) at the Atomic Energy Research Establishment, and in 1957 was appointed managing director of Atomic Power Constructions Ltd.

Elected a full Member of the Institution in 1946, Colonel Raby joined the Finance Committee in 1957, and in the same year was elected to the Council. He became a vice-president in 1958, and has recently been appointed to the Professional Purposes Committee.

Before his election to the Council in 1958, **Arthur Albert Dyson** had served for a year as a Trustee of the Brit.I.R.E. Benevolent Fund. He continues as a Trustee, and has recently joined the Finance Committee.

Educated at Leamington College, Mr. Dyson received his engineering training as a student apprentice with British Thomson-Houston Ltd. He then took charge of radio and sound reproduction equipment manufacture at the company's Newcastle factory, and in 1932 joined his present company, Erie Resistor Ltd., as works manager. He has been managing director since 1936 and became Chairman in 1958, he is also a director of the American parent company, Erie Resistor Corporation. He has been responsible for the company's expansion in this country, and in 1953 his work in connection with electronic components production for the Services was recognized by his appointment as an O.B.E.

Mr. Dyson, who is 52 years of age, was elected a full Member of the Institution in 1946.

Harvey Fisher Schwarz was born in Edwardsville, Illinois, U.S.A. in 1905, and studied at Washington University, St. Louis, graduating with a B.Sc. degree in electrical engineering in 1926. He then joined the General Electric Company, Schenectady, as an engineer, and in 1928 went to the Brunswick Radio Corporation as assistant chief engineer. This company subsequently merged with the Decca Record Company, and Mr. Schwarz came to England as chief engineer in 1932.

During the war the Decca Company took up the development of a c.w. hyperbolic navigation system invented by W. J. O'Brien, and Mr. Schwarz was closely concerned with its application for use by the Royal Navy. After the war the Decca Navigator Company was formed and Mr. Schwarz became its managing director in 1949, a position he holds today.

Mr. Schwarz was elected a full Member of the Institution in 1953, and in 1957 was appointed to the Finance Committee. He has been a member of the Council since 1958.

The Application of Printed Wiring to Development and Small Batch Production with Particular Reference to Television Equipment†

by

E. DAVIES‡

A paper read on 2nd July 1959 during the Institution's Convention in Cambridge.

Summary: Better utilization of engineering staff and a reduction of development time can be achieved by a new grade of labour which serves as a link between development engineers and the drawing office. These "translators" convert circuit diagrams and associated component schedules into wiring and component legend layouts for printed wiring boards. The choice of standards, method of translation, and the type of machinery which was specially designed for the automatic punching of holes, assembly of components, and soldering of boards, will be discussed.

1. Introduction

By 1956 it was apparent that printed wiring could offer considerable advantages in electronic equipment from the points of view of consistency of manufacture, of reliability and eventually of cost. It was therefore decided to design a new range of television studio and allied equipment incorporating these advantages and to develop any new design techniques and manufacturing methods necessary to achieve this end.

In the first instance, consideration was given to the influence of printed wiring in relation to the basic electrical and mechanical design of television equipment. The use of printed wiring in its most simple form results in a tendency to increase the area, but not necessarily the volume, of equipment by comparison with conventional forms of construction. Thus it became obvious that a new concept of packaging equipment would be necessary. Television apparatus is required for use in studio and outside broadcast operations, making it desirable to employ a common basic design with fittings which enable it to be used in either application.

The standard 19-in. rack type of mounting is used extensively in Studio and Master Control Rooms, whereas portable suit-case type equipment capable of being mounted on anti-shock fittings is needed for outside broadcast use. It was therefore decided to use a basic modular case size of 24 in. × 15 in. × $8\frac{5}{8}$ in. for outside broadcast use, enabling two of these units to be rack mounted, side by side, in permanent installations.

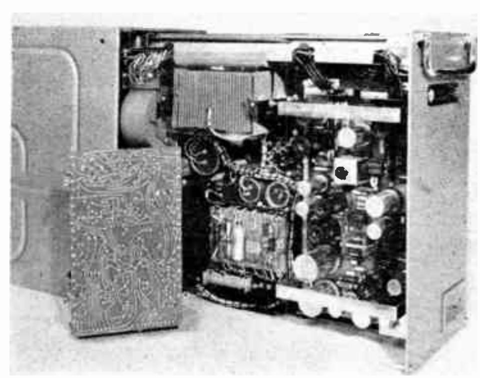

Fig. 1. Printed wiring case.

This new printed wiring case, shown in Fig. 1, is sub-divided into two by a central partition which, with the front panel, can be withdrawn from the case on runners. This form of construction gives the largest possible area for mounting printed wiring boards and is inherently suited to convection or forced air cooling; it also utilizes the volume of a 19 in.

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‡ Marconi's Wireless Telegraph Co., Ltd., Television Laboratories, Chelmsford, Essex.

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rack type cabinet much more effectively than the average pan chassis although the latter is still used for mounting some printed wiring equipment where the use of a printed wiring box is not desired.

With the above considerations in mind the next step was to investigate more fully the technical and economic aspects of using printed wiring. In order to get an appreciation of the technical performance of a video amplifier using printed wiring an existing design with an overall gain of 20 db, consisting of a three-stage negative feedback amplifier having 26 db of gain followed by an output stage having a source impedance equal to the 75-ohms load, was constructed on a "phenolic" board with etched copper conductors. The experiment was entirely successful, and except for a different setting of the capacitor adjusting the negative feedback loop phase characteristic, performance was identical with that obtained by conventional construction, but with the added advantage of an increase of level frequency response from 10 to 12·5 Mc/s.

With the establishment of a basic constructional policy supported by experimental evidence that the technical performance of printed wiring equipment would at least equal that of equipment using conventional methods of construction, a study was made of the tasks performed by all personnel engaged in the design and manufacture of equipment from initial conception to final test, with a view to simplifying communication within and between various departments, and to simplify the manufacturing processes.

As might be expected, some existing procedures were obviously redundant in respect of printed wiring, and some mechanization had to be provided in order to achieve shorter development and manufacturing cycles, and to achieve the expected reduction of manufacturing costs.

A study of the overall problem showed that the following action would have to be taken:

(1) To investigate methods for translating circuits to printed wiring.

(2) To introduce special staff for translation duties in order to conserve high-grade engineering and drawing office staff.

(3) To introduce standardization in respect of printed wiring.

(4) To eliminate the dimensioning so far as practicable in design and manufacture.

(5) To reduce unnecessary work and to eliminate human errors after initial checking of information by the extensive use of photographic methods.

(6) To eliminate as far as possible the need for general assembly drawings in the production of printed boards.

(7) To introduce mechanization wherever possible.

(8) To investigate raw materials and processes for producing printed wiring boards so as to ensure a high-quality product with regard to life, environment and ease of maintenance.

(9) To design special components where necessary, and to persuade component manufacturers to make items suitable for the 0·1 in. grid used in the radio and communications industry.

(10) To introduce a routine procedure for the manufacture of printed wiring boards for development and production.

The implementation of the above points will now be considered in greater detail.

2. Translation of Circuits to Printed Wiring and Component Legend Layouts

The need to conserve high-grade engineering and drawing office labour has been apparent for a long time, and with the introduction of printed wiring, the use of female labour to effect translation from circuit to component layout was thought to be possible. Experience soon showed that girls of about eighteen years of age educated to General Certificate of Education standards, without any engineering training other than that required to read a circuit diagram in order to associate circuit symbols and references to a component schedule, could rapidly become proficient in preparing a component legend and wiring layouts in accordance with the method described later.

It is of course, necessary to brief the translator in general terms on layout so far as crosstalk and stability are concerned, but engineering training is confined to a few basic rules; e.g., that a grid stopper must be in close proximity to the appropriate valveholder pin. Layout can then be safely left to the translator, who meticulously observes rules of standardization, and it is not long before her advice is sought by engineers faced with the problem of fitting a quart into a pint pot.

The professional engineer is naturally reluctant to admit that personnel untrained in circuit design can successfully devise a component layout, and in some instances engineers insist on producing a draft layout, but this phase soon disappears when it is realized that the tedious process of component and legend layout, with the restrictions of standardization, can be delegated; thus leaving the engineer free to indulge in creative circuit design. The performance specifications of modern television equipment are stringent, e.g., frequency response has to be maintained $\pm 0{\cdot}2$ db up to 8 Mc/s and crosstalk between adjacent signal inputs over the same bandwidth has to be of the order of -60 db.

An initial layout does not always result in precisely the desired performance, but since even a complicated circuit employing, say, eight double-triode valves can be translated in 7 to 10 days, there is no point in using other constructional techniques for first models. In most cases by noting any desirable mechanical and electrical changes to obtain the desired performance, a second translation, usually the original layout slightly modified, in most instances leads to the final design.

2.1. *Method of Translation*

A number of methods have been investigated, but space only permits a description of one preferred method which has been used successfully to translate over 100 television circuits to date.

For convenience, layouts are prepared at twice full-size and the basic aid is an accurate 0·2 in. matrix, printed on dimensionally stable polyester film which can be used indefinitely, since photomasters are prepared on plain semi-transparent polyester film affixed to either side of the matrix by adhesive tape.

Self adhesive silhouettes twice full size of the various size groups of axial lead components in the Preferred Components Catalogue are used to indicate the area occupied by a component, and the corners of the rectangle are used to locate the silhouette on the matrix. This automatically places black spots which represent the axial lead bending centre, accurately on the matrix. Other silhouettes in common use are shown in Fig. 2 and special silhouettes are made when necessary.

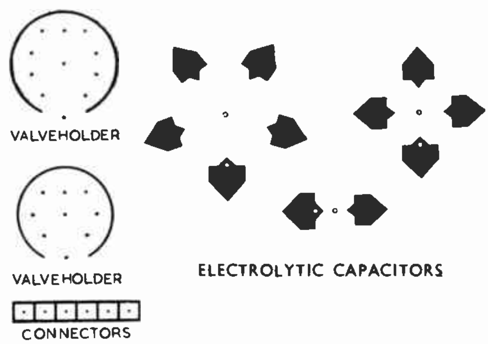
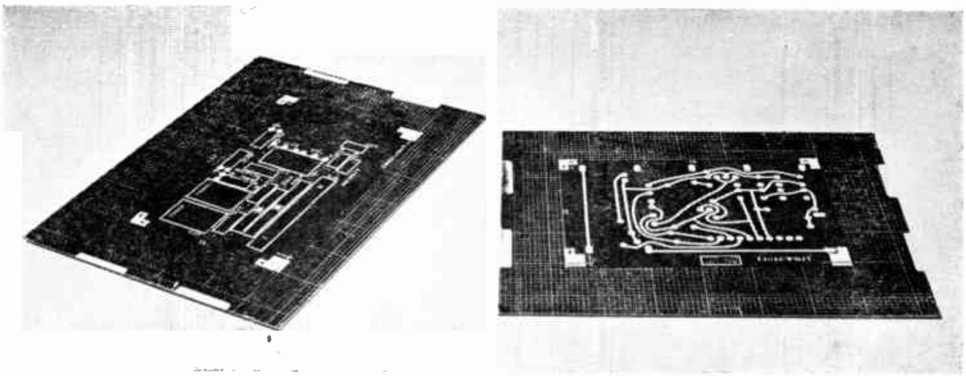


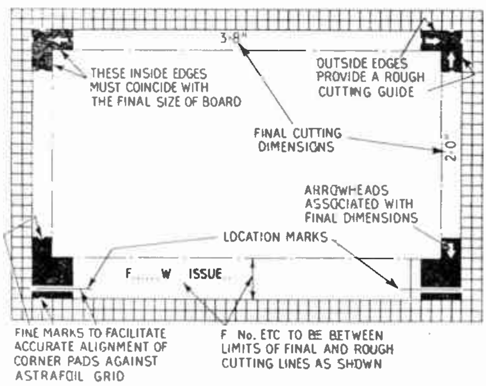
Fig. 2. Silhouettes of components in general use.

The silhouettes are put down in an area representing the final board, and in positions governed by physical and circuit requirements. When a satisfactory layout has been achieved, and each silhouette has been given its circuit identity by means of an appropriate transfer, the matrix and its associated polyester sheets are turned over, showing the underside of the silhouettes which have been previously numbered with their circuit identity.

Black silhouettes with small centre holes representing the standard 0·15 in. circular pads are then placed on the matrix at the exact points where component leads are situated. This operation is simplified by virtue of the fact that the intersections of the lines of the matrix are visible through the hole of a pad, and when the pad is correctly placed four equal quadrants are observed. The pads are then joined up by black adhesive tape 0·1 in. wide, representing the conductors according to circuit requirements. Where time or circumstances do not permit a solution involving no crossing of conductors, wire bridges are used on the component side to effect crossings, but in practice the number of



(a)



(b)

Fig. 3. (a) *above.* Glass masters of legend and wiring.
(b) *right.* Adhesive corner marks.

bridges used in relation to components is very small. When both component legend and wiring layouts have been checked, a process facilitated by the transparent nature of the matrix and its associated polyester sheets, the production glass masters of the legend and wiring layouts are produced independently and photographically reduced precisely 2-to-1 as shown in Fig. 3(a).

2.2. *Elimination of Dimensioning and Factors concerning Mechanization*

It will be appreciated that the method of translation just described reduces dimensioning to a minimum. Remaining dimensions are minimized by locating non-standard holes on the matrix after which it is only necessary to specify the size of the hole or the pattern of holes required. Thus a general assembly drawing is not necessary for the assembly of the basic printed board. Moreover, the exploitation of the 0·1-in. matrix and the standard 0·052 in. hole has made it possible to introduce mechanization.

Although the length and breadth of the board have been specified, and the area utilized to obtain optimum component layout, other production processes require information which does not appear on the finished board. Figure 3(b) shows adhesive corner marks which are used at the commencement of translation to define the finished area, in this example 3·8 in. × 2 in.

Important features of the corner marks are:

(1) The outer edges indicate the minimum size of raw material for the board.

(2) The inner edges indicate the finished size, and trimming to this dimension ensures that any contamination along the raw edges of the board by absorption of the etching fluid is removed from the finished product. The arrowheads are for dimensional purposes including reproduction on drawings.

(3) The corner marks are provided with fine marks to facilitate alignment with the master matrix, and the fine horizontal and crossed lines of the lower corner marks are used for location purposes in a 0·052-in. hole punching machine; they are also used for alignment of the negative in the printing frame.

(4) During production it is essential to identify the pattern and its issue number; this information is accommodated between the rough and final cutting limits on the bottom edge of the board.

2.3. *General Assembly Drawings*

The objective of substantially eliminating the need for a general assembly drawing has been achieved by the adoption of a component legend on the component side of the printed wiring board, and the associated component schedule. However, inspection requirements demand that the wiring pattern and the component legend are recorded on a drawing, and this is achieved without error by using a photographic method involving sensitized linen. The basic patterns are reproduced on this for inspection purposes, and any dimensions and assembly instructions that are not covered by standard translation procedure are added.

3. Standardization

The most important step towards standardization was the adoption of the 0·1-in. matrix as a standard for positioning all holes concerned with component assembly, since this simplified the problems of dimensioning and mechanization described elsewhere. The following basic recommendations are observed wherever possible, and serve to ensure that the end product is reliable and to allow reasonable latitude in the various processes which take place from translation to assembly of the board.

1(*a*) Recommended minimum conductor spacing to be 0·05 in. where potential difference between adjacent conductors does not exceed 250V (up to 2kV a *pro rata* increase is usually satisfactory).

(*b*) Minimum spacing to be 0·03 in. but only to be used where absolutely necessary because of production problems.

2(*a*) Normal conductor width to be 0·05 in.; this is suitable for currents up to 3 amperes with 0·0015 in. copper foil for a 20°C rise in temperature.

(*b*) Minimum width to be 0·03 in. but only to be used where absolutely necessary because of production problems. Coils may use narrower conductors but the reject rate may be rather high.

(*c*) Areas of copper greater than ¼ square inch must be cross hatched.

3. Hole size to be 0·052 in.

4(*a*) Normal circular pad diameter to be 0·15 in.

(*b*) Large electrolytic capacitors mounting pads to be of special shape and size to cater for location and mechanical rigidity (see Fig. 2).

(*c*) Width of conductor surrounding the 0·052-in. hole must not be less than 0·02-in. at any point.

5. Minimum distance from edge of board to 0·052-in. hole centre to be 0·1 in.

6. Protection against electrolysis of conductors of assembled board to be by application of not less than 0·003 in. of epoxy resin varnish.

7. Axial lead components to be inserted along either the length or breadth of the board.

8. Maximum board size to be 16·8 in. × 6·8 in. because of limitations of existing machinery.

3.1. *Axial Lead Components*

The author's Company had already introduced a standard Preferred Components Catalogue, from which designers select the majority of components required for conventional construction, and it was obviously desirable to use the same components wherever possible when using printed wiring. Since the utilization of a printed wiring board depends on the efficient use of its area, the axial lead components in the Preferred Components Catalogue were graded into nine basic sizes with appropriate lead bending centres.

3.2. *Special Components fitting the 0·1 in. Matrix and Standard 0·052-in. Hole*

Universal bus-bar. This component consists of three basic parts as shown in Fig. 4. Detail (a) is used as an earth bus-bar and the repetitive lugs pass through the printed wiring board to connect up points in the circuit which have to be earthed.

Detail (b) is used for h.t., l.t. or other supplies and is normally sandwiched between two of detail (a), and insulated by detail (c) which is made up from a suitable insulating material. The lugs of detail (b) connect up the parts of a circuit requiring a particular supply and up to two of detail (b) can be included in the sandwich. The lugs of details (a) and (b) are then arranged to follow sequentially along the length of the board.

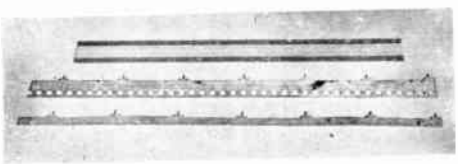


Fig. 4. Bus bar. Detail (a) earth; (b) h.t. etc.; (c) insulation.

The lugs of the two outers, detail (a), are in step along the length but spaced 0·1 in. apart, and this imparts great rigidity to the assembly when bolted together and soldered into the board.

The perforations on the top edge of detail (a) are used to mount the standard fixings as shown in Fig. 5. They are also used for mounting brackets, handles, etc.

Valveholders.—The majority of valves used in modern equipment are of the miniature type, and it is necessary to continue using a first class component proved over a number of years; valve holder manufacturers have co-operated in producing 7- and 9-pin versions of p.t.f.e. insulated valveholders with soldering tags suitable for 0·052 in. holes and brought out on a 0·1-in. matrix. For r.f. applications where leads on the 0·1-in. matrix are unacceptable because of the increased length, similar valveholders have been produced with straight soldering tags suitable for 0·052 in. holes; these of course need non-standard punching of the board.

Plug and socket connectors.—Although edge connectors making direct contact with the foil are used extensively by other companies, it was not considered a satisfactory method for general

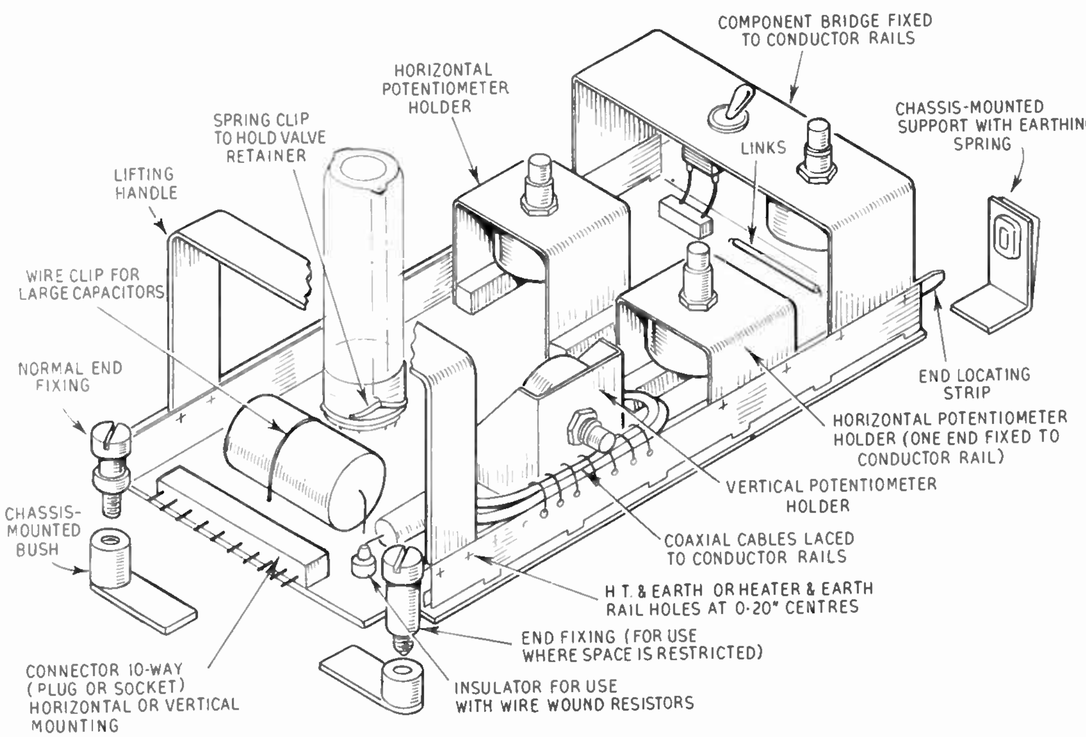


Fig. 5. Typical chassis showing standard fixings bracket and handle fitted to bus bars.

use in television transmission equipment. Component manufacturers have therefore produced a special 10-way plug and socket using standard "microcon" connectors, but with the normal soldering tags reduced to fit a 0·052-in. hole punched in 1/16 in. thick material.

When correctly mounted on a printed board, i.e. all contacts pressed home, the soldering tags turned over in contact with the foil, and a neat fillet of solder applied surrounding the lug, life tests with a plug and socket deliberately misaligned have shown that at least 20,000 insertions and withdrawals are obtainable before failure, which so far has always occurred on the lug between the soldered joint and the actual contact.

Coil formers.—Special coil formers have also been developed.

Printed wiring tags (Prov. Patent 10911/58). —These consist in effect of a split pin sprung into position in the 0·052-in. hole with the head supported above the board by a ceramic bead. These tags occupy very little space and can be placed at 0·1 in. intervals if required; the beads may be colour coded, and the strength of the assembly is such that under excess tension a wire soldered to the tag will invariably break before damage occurs to the tag or its soldered connection to the foil. They are used mainly in lieu of plug and socket connections where the latter are not desired.

4. Mechanization

A large number of holes have to be made in predetermined positions on printed wiring boards, and the method by which they are made is largely a matter of capital investment and philosophy. The philosophy of the team engaged in introducing printed wiring into television transmission equipment has been:

(1) The capital investment should be as small as possible consistent with producing holes accurately with regard to size and position, at a speed not less than three times faster than present methods.

(2) Cumulative errors of positioning must be avoided, so that special components such as the bus bars with multiple lugs extending over some 18 in. can be inserted freely into the finished board.

(3) Special templates or other jigs should not be necessary.

(4) Automatic operation can be incorporated.

(5) Simplicity and reliability are of paramount importance. It was considered that simplicity would reduce cost and improve reliability, and from the point of view of capital investment a number of relatively low priced machines, rather than a single comprehensive one, would be more attractive.

4.1. *Punching Machine*

With the above philosophy in mind, the machine-tool designer decided to punch the holes with a single pneumatically-operated punch head, with the printed wiring board mounted in a carriage capable of X and Y coordinate movement. Accurate positioning of

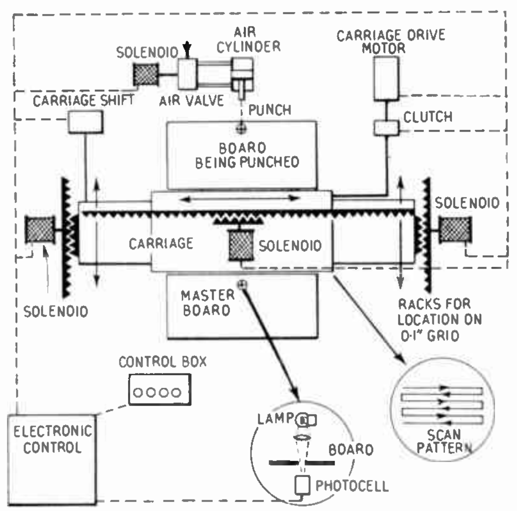


Fig. 6.(a) Diagrammatic representation of punching machine manually operated.

the carriage in both X and Y directions is effected by the use of precision 0·1-in. racks mounted on the framework of the machine, and indexing the carriage by engaging solenoid-operated racks on the carriage with those on the framework, as shown diagrammatically in Fig. 6(a). The board to be punched is clamped in the movable carriage, and accurately positioned with the aid of a magnifying optical system. Referring to Fig. 3(b) the + sign on the right-hand lower corner mark of the printed board, is made to coincide with the + sign of the optical system, and the first clamp is operated, which then enables the board to be pivoted. The – sign of the left-hand lower corner mark is then observed through the optical system and the board pivoted until the – sign is coincident with the horizontal line of the + sign of the optical system. It will be appreciated that the board has now been accurately located on a matrix defined by the precision 0·1-in. racks, and that these racks are simulating the original polyester film matrix used to determine the component layout.

If only one board is required, the machine is manually operated and the carriage positioned so that the punch head is over a circular pad requiring a 0·052-in. hole. The punch head is operated pneumatically but is controlled by a solenoid-operated valve which is energized after the X and Y indexing solenoids have been operated, the latter giving precision to the hitherto rough manual positioning of the carriage. Where two or more identical boards are available, a second unpunched board is clamped relatively accurately in the control position as shown in Fig. 6(a), and a beam of light representing the punch is focused on to the board. The carriage is positioned manually so that the light beam falls on the centre of the pad to be punched, and indexing and punching occur as described above. When the punching of the first board is complete it is inspected to determine that all pads are punched and that no spurious holes have been inserted. This board can then be transferred to the control position and the beam of light can then pass through the punched holes to the photocell as shown in Fig. 6(b). Blank boards can then be located in the punching position as described, and the carriage driven automatically so that the board is scanned along its length alternately from right to left and left to right inching forward 0·1 in. after each traversal; total inching and traversal are controlled by micro-switches set for the appropriate length and breadth of board. Whenever the photocell is energized by the beam of light passing through a punched hole in the control board, the carriage is braked, indexed, and the punch operated as previously described. The scanning rate of the prototype machine is approximately 2 in. per second, and this is not materially affected by the number of punched holes that have to be made. The production machine however, scans at 2·56 in. per second, and has the added refinement that scanning of any lines of the matrix not requiring holes can be eliminated by coding holes on the master board in the waste edge material, so that the inching mechanism continues to operate until a line requiring a hole is reached. Location of the board in the machine has also been simplified by the addition of two holes, accurately positioned on the matrix at an earlier stage

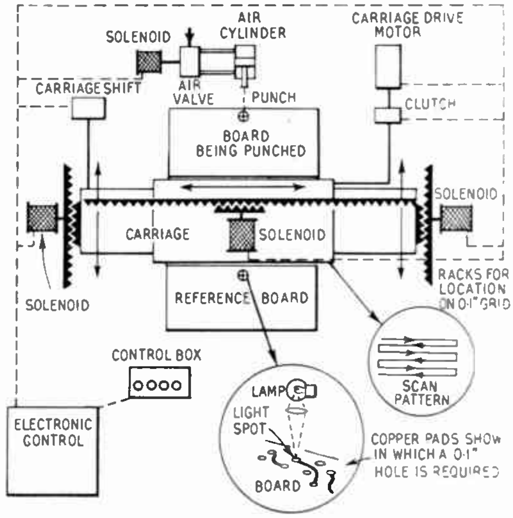


Fig. 6. (b) Diagrammatic representation of punching machine. automatically operated.

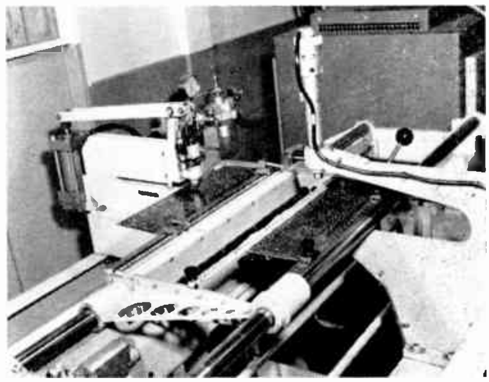


Fig. 6. (c) Punching machine.

of production, and the board is then placed in the punching machine using the two holes in conjunction with dowels.

4.2. *Punching Machine Electronic Control System*

Figure 8 is a simplified circuit diagram of the punching machine control unit. V1 to V4 inclusive are thyratrons, capable of directly operating the Rack, Inch, Punch, and Clutch solenoids respectively. T1 – T5 are identical trigger units for driving the thyratrons and are of conventional design; they amplify, shape, and limit the input pulses and provide an output of low source impedance. Likewise D1 – D3 are identical adjustable delay units of conventional design, providing shaped and delayed pulses with respect to the input, and having a low source impedance output. The function of the delay units is to ensure adequate time for operation of solenoids, relays and the pneumatically operated punch. The control system operates as follows.

4.3. *Automatic Control*

SW1 will be switched to "A"—automatic. When the start button (SW4) is pressed, both RLA and RLC are operated and held in via RLC2, SW5 and SW7. RLG5 by-passes SW5 and SW7 during inching to ensure that the machine may only stop during a scanning cycle. The RLC coil is energized also via MR1 which prevents circulating currents around the loop RLA and RLC on switching off, thus providing short release times for both RLA and RLC. Having now energized both RLA and RLC, the carriage drive motor is brought into operation via RLA1, 2 and 3. RLC1 brings in the photo-conductive cell, RLC3 makes available the "Auto" inching circuit and RLC4 removes the earth from the grid of V4, leaving V4 in an ionized condition, and also makes available RLF for an operation at the end of the first scan. The carriage is then in motion and remains so until a hole appears under the light spot. Light is then passed to the photo-conductive cell and causes it to conduct heavily, producing an input pulse to T2 via RLC1, RLD2 and RLG2; the output pulse of T2 causes V1 to ionize, its anode voltage falling from 300 volts to 10 volts de-ionizing V4. The action of V1 ionizing causes the rack to be energized and holds the carriage in the correct position on the 0·1-in. matrix whilst de-ionizing disengages the motor drive via the clutch.

The output pulse of T2 is delayed via D1. The delayed output pulse of D1 causes V2 to ionize and operate the punch circuit, at the same time causing V3 to de-ionize. The delayed output pulse of D2 causes V3 to ionize, thus de-ionizing V2 and returning the punch. Finally the delayed output pulse of D2 is further delayed by D3 before it causes V4 to ionize, thus re-engaging the clutch and de-ionizing V1 to release the rack.

The carriage now moves on until light is again passed via a hole in the master board to the photo-conductive cell, causing another punching cycle to take place.

Since RLF is always de-energized when the start button is pressed, the scan is always in the left to right direction: when the first scan is complete the end-stop micro-switches SW11 and SW12 are tripped. SW12 operates RLF which then holds in via RLF1 and SW13. RLF then operates RLB via RLF2 contacts, which in turn reverses the drive motor. The carriage will not start to scan in the opposite direction yet, since at the same time that SW12 operates, SW11 switches in RLG very quickly, in order to lock the rack, and disengage the clutch by means of the RLG2 contact producing an input to T2. RLG is made to operate quickly by means of the high frequency boost circuit R21 and C8. At this stage V3 is still in an ionized state and V2 de-ionized. RLG1 will have operated along with RLG3, RLG4 and RLG5, RLG5 prevents either the stop button SW5 or the finish-scan micro-switch SW7 operating during inching. The inch circuit is therefore available at the anode of V2, and after a short time delay provided by D1, V2 will be ionized and V3 de-ionized thus energizing the inching solenoid valve and therefore initiating the inching cycle. Once the carriage has moved over 0·1 in., the stop-inching micro-switch SW9 will be tripped, ionizing V3 by way of trigger unit T4 and at the same time de-ionizing V2, thus returning the inching mechanism back to its start position; at this point the start inching micro-switch will be re-operated, having been opened during the inching cycle, and will ionize V2 by way of T3 operating via the RLG4 contact.

The machine will now have made one complete inching cycle. If now that the second inching cycle has been initiated a "coding" hole appears under the spot of light towards the end of the first half of the inching cycle, the clutch will be re-engaged. This operation is initiated by the photo-conductive cell producing an impulse at the grid of V4 via RLC1, T1 and RLG3. The clutch is now engaged, and the motor already having been reversed, drives the carriage away from the right-hand end-stop micro-switches SW11 and SW12.

RLG will now be released only when the first half of the inching cycle is complete, since RLH1 is still holding in and will do so until the stop-inching micro-switch SW9 is operated. RLH now drops out thus releasing RLG whilst V2 is de-ionized, thus ensuring that RLG1 operates at a time when no current is flowing in the inch circuit in order to ensure completion of the inching cycle, and reject any possibility of random punching. The machine is now operating in its punching condition and scanning from right to left. On reaching the end of its scan, SW13 the left end-stop micro-switch will be operated, dropping out RLF and returning the motor to its forward direction, also initiating the inching cycle by operating relays RLG and RLH.

The inching cycle will proceed exactly as before, finishing only when the necessary "coding" hole appears under the light spot. When the machine has scanned the whole board and the final inching operation has been initiated, the finish-scan micro-switch SW7 is operated; at the completion of this final inching cycle RLH and then RLG are de-energized, so opening the hold-in circuit of RLC and RLA, thereby stopping the machine.

4.4. *Manual Control*

The auto-manual switch SW1 will be switched to manual, operating RLD. The punching cycle is initiated by the push button SW3 in this case, the cycle being completed in the same manner as in the "auto" condition, except for the clutch being replaced by R14 in the anode circuit of V4. The inching cycle is again very similar to that of the "auto" condition, this time instead of being initiated by the end-stop micro-switches, SW11, 12 and 13, it is initiated by the inch push button SW2 which operates RLE. RLE will "hold in" by way of RLE1 and the stop-inching micro-switch SW9, whilst RLE2 operates RLG, which, as in the "Auto" case, controls the sequence of inching. Manual inching stops once the inch push button SW2 is released, and the stop-inching micro-switch SW9 breaks the hold in circuit of RLE. As RLE drops out RLE3 ionizes V4 via trigger unit T5 and so disengages the rack.

4.5. *Assembly of Components*

Although the automatic assembly of components into a printed wiring board is highly desirable, the very wide range of components used for television equipment put the design of suitable machinery well outside the author's terms of reference. However, the reliability of

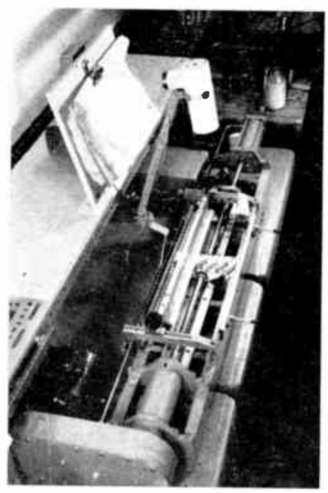


Fig. 7. Assembly machine.

printed wiring boards depends quite considerably on the ability to insert components, and solder them into position, ensuring that the under side of the component is in intimate contact with the board, so that any pressure subsequently exerted from above the component does not cause the copper foil to be pushed away from the board. To meet this requirement a machine was designed (Fig. 7), capable of bending over the ends of leads or soldering lugs into intimate contact with the copper pads, provided the component was firmly held down on

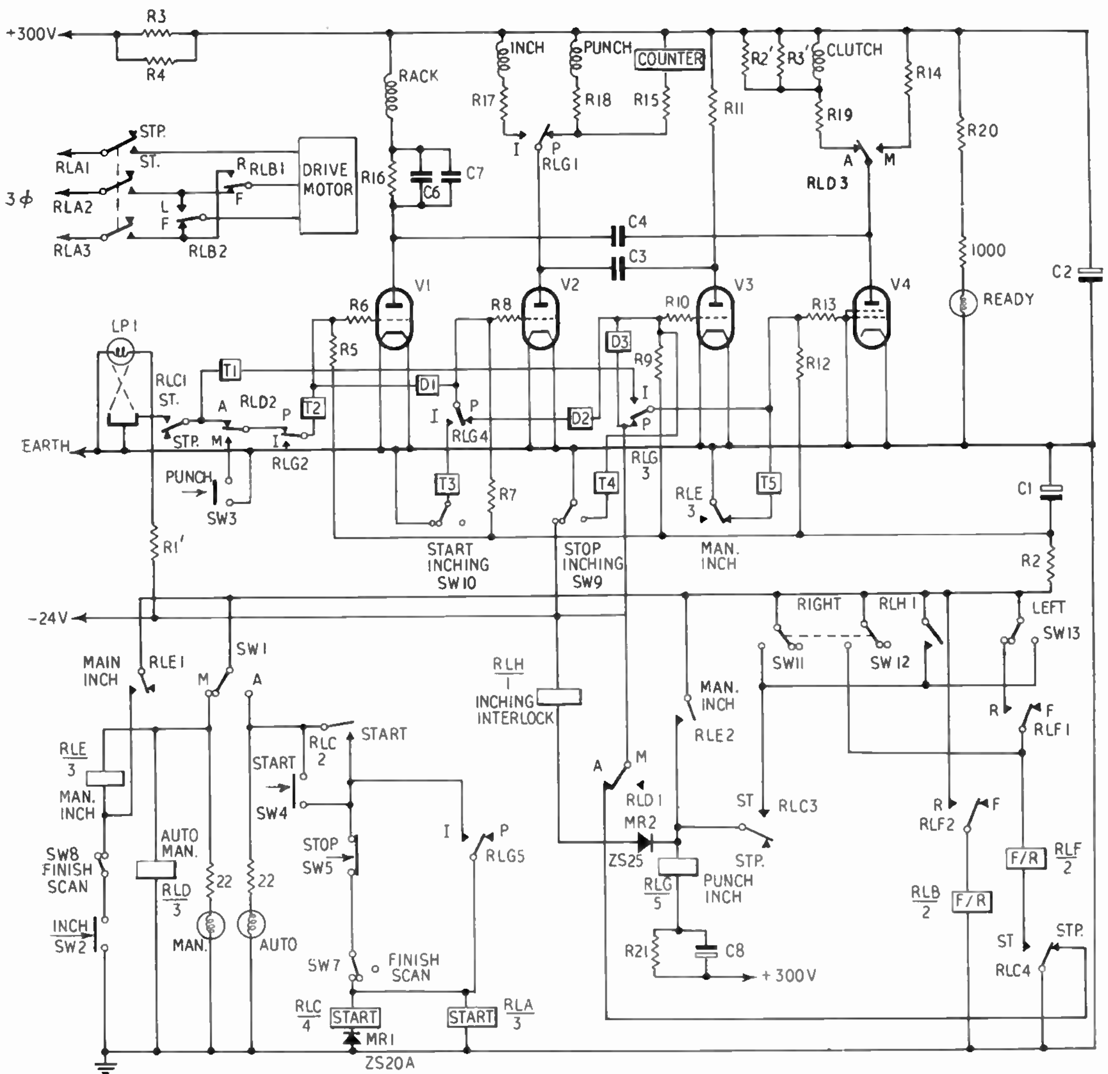


Fig. 8. Simplified circuit of punching machine control mechanism.

the board during the bending operation. The wire blade which bends the leads over is placed at 45 deg with respect to the length and breadth of the board, so that axial lead components cannot be rolled out of the board as would be the case with leads bent at 90 deg to the length of the body of the component.

In the first instance a machine was devised for straightening the leads of axial components and bending on the desired centres, but this was abandoned as it was found that leads could be more quickly bent by hand, and that the sloping of the lead as shown in Fig. 9, rather than having a sharp shoulder, was if anything advantageous in precluding the possibility of detaching a copper pad by inadvertent pressure from above.

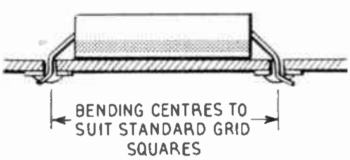


Fig. 9. Method of lead dressing for axial components.

A lead cropping machine (Fig. 10), ensures that the correct amount of lead protrudes through the board, so that when the end is turned over it cannot extend beyond the pad sufficiently to cause an unwanted connection with an adjacent pad or conductor.

4.6. *Soldering*

The mass soldering of components represents the greatest saving of labour, and practical experience indicates a greatly increased immunity from fracture of the copper foil during replacement of faulty components. Various methods were tried using solder baths, none of which provided satisfactory results, but with the advent of the "flow soldering machine" in which the assembled board is passed over a wave of molten solder, good and repeatable results were obtained after taking due care as regards cleanliness and technique of flux application. The solder wave ensures that the board is in contact with the solder for the minimum time (approximately two seconds), and the recirculation and mass of solder prevents any appreciable solder contamination. Weekly analysis of the solder determines at what stage the solder ingredients have to be varied, or totally replaced. Normally a 35-to-65 ratio of lead to tin is used at a temperature of 265°C±5°C, with a carriage speed of 24 in. per minute. On the basis that component leads and soldering lugs should have good initial solderability, considerable care is taken to keep handling to a minimum, and the etched board is protected on the copper side by the application of a coat of flux varnish.

4.7. *Summary of Improvement in Production on a Laboratory Basis due to Mechanization*

The time taken in manual, semi-mechanized and mechanized production of a specimen printed wiring board is shown in Table 1. The board consists of 18 resistors, 8 capacitors, 1 wirewound resistor, 3 valveholders, 2 capacitor clips, 1 h.t. supply rail, 11 connector blocks and 8 wiring bridges—a total of 53 components.

Table 1

	Method			
Operation	Manual	Semi-Mechanized	Mechanized	Maximum increase in productivity
Pierce board: 230 holes	13 min 10 sec	11 min 10 sec	7 min	1·88
Prepare components: qty. 53	8 min 30 sec	4 min 15 sec	No automatic machinery available	2·0
Assembly of components into board after methodizing into logical sequence	20 min	9 min 10 sec	No automatic machinery available	2·18
Soldering of board: 230 joints	15 min 20 sec	—	1 min approx.	15·0
Total time for all operations:	57 min	24 min 35 sec with manual punching but excluding soldering.		2·22
			21 min 25 sec with automatic punching.	2·8

Note. Time to prepare methodizing sheet 20 min, resulting in improvement in semi-mechanized assembly time of approx. 2:1.

5. Investigation of Raw Materials and Processes

The choice of readily available materials is still very limited and falls into two main classes—

(a) Copper clad phenolic paper based material.

(b) Copper clad epoxy resin bonded glass fibre material.

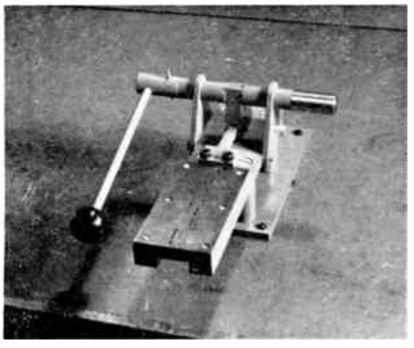


Fig. 10. Lead cropping machine.

The specifications to which these materials are manufactured are, in general, inadequate for high-grade printed circuit work. The following draft specification for the epoxy resin based material has been discussed with manufacturers as representing the minimum acceptable standard with a view to eliminating defects which have proved wasteful in manufacturing printed wiring boards.

5.1. *Electrical Characteristics*

Power factor and permittivity should be measured by Hartshorn and Ward method at 40 Mc/s as well at 1 Mc/s.

5.2. *Bowing*

Where the bowing is predominantly cylindrical, the deviation measured as the maximum perpendicular distance between a chord of the curve and the board, shall be measured over the greatest lengths of uniform maximum curvature, and shall not exceed the values given below.

Length of chord	10″	20″	30″	40″	50″
Deviation	0·02″	0·17″	0·58″	1·37″	2·7″

Where the bowing is similar in degree in two directions at right angles, the deviation shall be measured over the greatest length of uniform maximum curvature in either direction, and shall not exceed the values given below.

Length of chord	10″	20″	30″	40″	50″
Deviation	0·015″	0·13″	0·44″	1·0″	2·0″

Further, there shall not be more than one change of sign of curvature along any one edge, and changes of sign may not occur simultaneously in any two edges at right angles to each other.

5.3. *Warp*

Warp shall be measured by offering the sheet of material up to a vertical flat surface so that three corners are touching it, and measuring the separation of the fourth corner and the flat surface. In performing this measurement, the sheet shall only be held by the corners with the minimum force exerted to hold the sheet in position. Where the bow in the sheet is uniform the separation shall be not greater than $\frac{1}{8}$ in. × area of the sheet in square feet.

Where the curvature of any edge changes sign along that edge the separation shall be not greater than 1/16 in. × area of the sheet in square feet.

5.4. *Pinholes and Inclusions in the Copper Surface*

Of diameter smaller than 0·010 in.—These shall have an incident rate of not more than 8 per sq ft average, and there shall not be more than 15 in any 1 sq ft.

Of diameter greater than 0·010 in.—These shall have an incident rate of not more than one per 2 sq ft and there shall not be more than 1 in any 15 in. square.

There shall be no pinholes or inclusions of greater diameter than 0·030 in.

Dents in the copper surface shallower than 0·002 in.—These shall have an incident rate of not more than 10 per sq ft average and there shall not be more than 15 in any 1 sq ft.

Dents 0·002 in.—0·004 in. deep.—These shall have an incident rate of not more than 1 per 2 sq ft. average and there shall not be more than 1 in any 1 sq ft. There shall be no dents of greater depth than 0·004 in.

5.5. *Local Effects*

The laminate shall not show any substantial signs of resin starvation or delamination as manifest by light areas, except where these result from the effect of the dressing on fibre joins, in which case the areas shall not be larger than ½ in. in diameter.

The laminate shall not show any marked colour change over the sheet, nor shall there be any colour changes on the face adjacent to the copper, which is revealed on etching away the copper, which can be readily perceived through a coat of epoxy varnish, applied over it. Any bumps on the copper surface shall—

(a) not exceed 0·0015 in. in height.

(b) be caused by interlaminate inclusions or blistering.

The criterion for the presence of interlaminate inclusions of an objectionable nature shall be the presence of a light area visible on the side of the material remote from the copper coincident with the bump.

Any other effects such as rippling on the copper surface shall—

(a) not exceed 0·001 in. total deviation;—measured perpendicular to the board.

(b) not cause more than 10 per cent. loss of adhesion when compared with a flat area adjacent to the effect.

5.6. *Adhesion*

Adhesion shall be determined by the perpendicular pull off force for a pad, of 0·15 in. diameter etched in the copper with a hole 0·05 in. —0·06 in. drilled or punched through the centre, after the number of solderings given below. A soldering is defined as the application of a soldering iron at 250°C ± 10°C for a sufficient time to solder the complete surface of the pad in the first instance, and to completely melt the solder thereon at subsequent solderings.

No. of solderings 9

Pull off strength say 40lb for glass fibre board.
say 20lb for phenolic board.

5.7. *Surface Condition*

The surface of the copper must be completely free from any tarnish or corrosion which will not clean off completely with pumice powder and water to leave a uniformly clean surface.

5.8. *Punching*

The material shall be capable of being punched at room temperature without delamination or lifting of the copper

5.9. *Peel Strength and Pull-off Strength*

The draft specification has been well received and it is anticipated that further progress will be made by copper clad board manufacturers now that the more specialized problems have

Table 2

Sample	Type of Material	Average peel strength of ⅛″ wide strip, material as manufactured	Average pull-off strength of 0·15″ diameter pad after 9 solderings at 270° C
		lb.	lb.
(a)	Glass fibre	1·55	56·2
(b)	„	0·62	43·5
(c)	„	1·03	22·7
(d)	„	1·15	57·4
(e)	Paper based	1·0	18·8
(f)	„	0·725	19·8
(g)	„	0·97	24·5
(h)	„	0·59	29·0
(j)	„	0·96	26·0
(k)	„	1·37	23·8

been explained in detail. Probably the most important parameter, from the point of view of a customer, is the pull-off bond strength of a copper pad after repeated soldering, and it is doubtful whether there is any correlation between this and the popular 1-in. wide strip peel test; in fact an adhesive which gives maximum peel strength is unlikely to provide maximum pull-off bond strength. In order to establish the relative merits of different materials as made by various manufacturers test patterns were devised permitting the maximum number of tests in the minimum area so that averages could be taken without material variation being significant. Table 2 indicates the results obtained, and further work is being done as regards bond strength at elevated temperatures over long periods.

As a result of the above tests one manufacturer co-operated in producing a sample of paper based board in which the adhesive was not modified to give maximum peel strength, and it was found that the number of times that a component could be replaced by relatively unskilled personnel, increased from an average of 55 to 148.

5.10. *Contamination due to Etching*

With regard to production processes it has been established that removal of a border of not less than 0·2 in. from the finished board ensures complete safety as regards contamination during etching provided that there is no resin starvation which might cause absorption.

5.11. *Reduction of Photomaster to Standard Size Negative Master*

This is accomplished by means of a high-grade camera, and an accuracy of $\pm 0{\cdot}003$ in. can be achieved in a length of 16 in. Using litho photographic plates variations of exposure and development can between extremes result in a conductor width variation of $-0{\cdot}006$ in. and $+0{\cdot}001$ in., but a maximum variation of 0·001 in. can be achieved in practice by the use of an exposure control pattern (See 5.14.).

5.12 *Production of Negative Master*

This uses the principle that the degree of development of a litho plate will be accurately determined by the extent to which it reproduces a grey scale.

5.13. *Production Negative Master*

This master is made from the original negative master in two stages, using litho photographic and contact printing. No greater tolerances than in 5.11 will be experienced at each stage as regards exposure and development provided a vacuum frame is used to ensure good contact. In practice, provided the exposure and development processes are similar at each stage, the tolerances cancel, and it is envisaged that the use of a transmissive grey scale will assure cancellation. Thus the accuracy of conductor width on a production negative master will be retained at 0·001 in.

5.14. *Board Printing and Etching*

The variation of the conductor width in respect of exposure of the resist from normal to four times the normal period is less than 0·0005 in. and can be ignored. To ensure correct etching, an etching pattern (Fig. 11) is

Fig. 11. Etching pattern.

used; it consists of a frame and bars, the latter being of progressively increased width starting at 0·002 in., and having a gap of 0·003 in. at the end remote from the 0·002 in. bar. This is used to ensure good focus when making the master negative.

6. Acknowledgments

In conclusion the author would like to pay particular tribute to Messrs. E. O. Holland, R. H. Oddy, R. W. Fenton, and D. W. Spurgin for their joint efforts in establishing the overall system of design and production, and to Mr. G. P. Surridge for his valuable contribution on material specifications and tests and production control. The useful advice and criticism of the Printed Circuit Standardization and Advisory Committees of the Company is also acknowledged. The author is indebted to Mr. B. N. McLarty, Engineer-in-Chief of Marconi's Wireless Telegraph Co. Ltd. for permission to publish this paper.

NEW BRITISH STANDARDS

The following is a selection of the new and revised British Standards on subjects of interest to members which have been issued during recent months. The Brit.I.R.E. has been represented on the Technical Committees concerned with preparation of those Standards marked with an asterisk(*). Copies of the Standards may be obtained from B.S.I., Sales Branch, 2 Park Street, London, W.1, at the prices indicated.

B.S. 350 : Part 1 : 1959. **Conversion factors and tables (basis of tables; conversion factors).** *Price 15s.*

One of the most thumbed reference books in use by science and industry—B.S. 350, Conversion factors and tables—is being revised, and a first part has now been published in a 114-page, fully indexed volume. The standard will be much enlarged in scope by its revision, and when this has been completed it will cover, broadly, units, their abbreviations, conversion factors and detailed conversion tables for a wide range of subjects falling under the general headings of metrology, mechanics and heat.

B.S. 530 : 1948. **Graphical symbols for telecommunications. Supplement No. 6 : 1959, Services' preferences and additional symbols.*** *Price 3s.*

This new Supplement to B.S. 530 will meet the needs of the many users of that standard who are either in the Services or connected with the supply of equipment to them. The Supplement does not constitute part of the standard proper, but relates entirely to the special requirements of the Services. It gives certain symbols additional to those in B.S. 530 and the first five Supplements, indicates Services' preferences concerning alternative symbols, and depicts a few deviations from B.S. 530 which the Services find necessary.

B.S. 905 : 1959. **Interference characteristics and performance of radio receiving equipment for aural and visual reproduction.*** *Price 12s. 6d.*

This revised publication brings up-to-date the first (1940) edition of B.S. 905; it specifies requirements which should be complied with in the design of sound radio and television receivers in order to reduce (a) interference caused by them and (b) their susceptibility to interference other than that picked up by the aerial/earth installation. It deals also with anti-interference and communal aerial systems.

Methods of test for determining compliance with the various requirements of the standard are specified in detail and the standard carries a recommendation on the choice of intermediate frequencies for television receivers, f.m. sound broadcast receivers and combined television and f.m. sound broadcast receivers. Four appendices deal separately with: "Recommendations for protection against atmospheric electricity", "The standard reference aerial for long and medium wavebands", "Measuring equipment" and "Measurement of oscillator voltage appearing at the aerial terminals of television and f.m. sound broadcast receivers".

B.S. 2112 : 1959. **Fixed carbon resistors for use in telecommunication and allied electronic equipment. Part 1 : General requirements and tests.*** *Price 10s.*

This standard applies to fixed carbon resistors having a dissipation not exceeding 3 watts at 70°C and a rated resistance value of not less than 10 ohms and not greater than 10 megohms. The resistors are intended for use over the ambient temperature range −40°C to +100°C in one of the humidity classes (H1, H2, H3 or H3A) of B.S. 2011, "Basic climatic and durability tests for components for use in radio and allied electronic equipment". Part 2, which is to follow, will give a list of standard sizes, ratings, etc., of resistors. An Appendix gives the standard colour code for resistance, tolerance and grade of resistor.

B.S. 2134 : Part 1 : 1959. **Fixed electrolytic capacitors (aluminium electrodes) for use in telecommunication and allied electronic equipment. (Part 1 : General requirements aud use.)*** *Price 7s. 6d.*

Part 1 of this standard deals with general requirements and tests. Part 2—to be published later—will specify sizes, ratings, etc., of a standard range of electrolytic capacitors. Use of this standard (as with others in the series) requires reference to B.S. 2011 (see above) which fully describes a range of tests to which components may be subjected in accordance with the requirements of the relevant standards for the individual components.

B.S. 3192 : 1959. **Safety requirements for radio (including television) transmitting apparatus.*** *Price 6s.*

The requirements specified for design, construction and electrical performances in this new standard are those necessary to prevent danger arising from the connection of apparatus to the supply mains and not, for example, from lightning. It excludes apparatus to be operated by skilled personnel, and apparatus for use in merchants' ships or civil aircraft for which requirements are laid down by the relevant authority.

The standard deals with the protection of personnel from electric shock and radio-frequency burns, and from flying glass caused by the implosion of cathode-ray tubes. To avoid overheating of the apparatus—with consequent fire hazard—limits on its temperature rise in the event of component failure are specified. Attention is drawn to the possible danger to the health of personnel which may be caused by X-radiation from high voltage equipment, and to the possible dangers arising from microwave radiation.

Printed Circuit Reliability and Flammability †

by

D. W. HEIGHTMAN, MEMBER ‡

A contribution given on 2nd July 1959 during the Institution's Convention in Cambridge.

Summary: Printed circuit television receivers show reliability at least equal to that of conventionally wired receivers. Certain valve or component failures could result in rather serious burning of panels. An investigation into the problem is described. A simple method of flux application and dip-soldering is described which has been found to give better reliability than conventional methods.

1. Introduction

A year's experience in production and field use of printed circuit television receivers showed, by statistical analysis, that, in general, the reliability was at least equal to that of conventionally wired receivers. However, in a small percentage of cases, certain valve or component failures could result in rather serious burning of panels. This was a consequence of decoupling resistors overheating when the valve or component fault produced a short circuit. This contribution describes an investigation into this problem and the solution resulting.

Another aspect of reliability is that of making satisfactory joints by dip-soldering. As an alternative to more sophisticated processes, a simple method of flux application and dip-soldering, which has been found to give consistent results on large scale production, is described. Field experience has shown the reliability of such joints to be rather better than that of conventionally-wired receivers.

2. Non-inflammable Resistors for Printed Wiring

The heat from overloaded resistors can cause a minor conflagration on conventional radio and television apparatus but under certain conditions can result in serious burning on printed circuit panels.

The reasons for the differences of effect are many, but probably the main ones are:

(a) The resistors are usually mounted close to the S.R.B.P. panels.

(b) The laminated panels are inflammable once the ignition point is reached.

(c) Components are often coated in wax which is likely to run on to the board during dip-soldering, thus adding to the fire risk.

(d) Vertical mounting of printed boards can cause the flames to spread.

The usual cause of overload is a short circuit fault, in a valve or component, at a high potential point which is decoupled by a low value, low wattage resistor. The resistor overheats and any wax which is on either the resistor, panel, or adjacent components, begins to vaporize. If the resistor temperature is sufficiently high, the vapours burst into flame and the whole panel may be damaged beyond repair. Thus the consequential damage is far more costly to make good than the original faulty part.

Experiments with various commonly-used types of resistor showed that, in most cases, they were impregnated with wax or varnish which was inflammable. The wax impregnation was necessary for long term stability in the resistor characteristics.

Some resistors, having a high thermal capacity, heated up slowly, thus bringing the wax vapours to ignition point when the resistor eventually glowed red hot.

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† Manuscript received 26th June 1959. (Contribution No. 24.)

‡ Technical Director, Radio Rentals Ltd., Technical Centre, Wembley, Middlesex.

U.D.C. No. 621.396.62

Desirable characteristics for decoupling resistors are, therefore:—

(1) Non-inflammability;

(2) Almost instant disintegration on overload.

Suitable resistors were found which met these requirements; such a resistor, under overload conditions exploded, necessitating replacement but saving a costly and possibly dangerous fire.

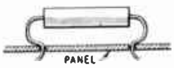

Fig. 1. Resistor end-wire forming to allow for stand-off from printed wiring panel.

At this stage, the main problem had been solved, but when the resistor disintegrated, a carbon deposit was left on the panel and adjacent components. This effect was reduced to acceptable limits by spacing the components from the panel by $\frac{1}{8}$ in. The resistor end-wires were formed as shown in Fig. 1, thus allowing the assembly operators readily to insert the resistors on panels at the correct stand-off distance. The form adopted for the wires gives a clip-in action which satisfactorily retains the resistor until it is fixed by the dip-soldering process.

3. Fluxing

One of the problems in preparation, prior to dip-soldering, is the satisfactory fluxing of the panels. The following method has given very consistent results in large scale production.

A resin/alcohol solution is sprayed onto the panels at low pressure, the panel being held stationary whilst the spray gun traverses the length of the panel. Spraying is done at low pressure to avoid atomising the flux and so creating large volumes of "mist." The pressures used are about 10 lb/sq. in. air pressure and 2 lb/sq. in. fluid pressure. In the present machine two spray guns are used to flux either two or four panels depending on their size. The spray guns are traversed by means of an air cylinder and are mounted on guide bars. The length of traverse is adjustable, by means of air valves, to cater for different lengths of panel.

After being fluxed the panels are left for ten minutes before dip-soldering, to allow the flux to dry to a certain extent. If this is not done the flux is too mobile and contains too high a proportion of volatile agents. The flashing-off of the volatiles drives the flux away from the copper areas and poor soldering is the result. If the flux is too dry the solder displaces it bodily and poor soldering again results.

4. Dip-soldering

Two solder baths are used for dip-soldering (but only one operator is necessary); the first bath is to tin the copper and pre-heat the assembly, and the second bath to complete the soldering operation. The surface of the solder baths is maintained dross-free by means of a stainless steel wiper. The panels are floated on the surface of the solder by the operator, and are moved to and fro to release any entrapped vapour and provide a washing action of the solder against the copper areas. The panel is also rocked to counteract the warp produced in the panel by the heat of solder so that all parts of the board are brought into contact with the solder. Wax is applied to the surface of the second solder bath and acts as a wetting agent, so improving the uniform quality of the soldering. No automation is used in this process and it is doubtful if it would contribute a cost saving.

The temperature of the first solder bath is maintained at 220°C and the panel is dipped for five seconds in this bath. The second bath is maintained at 235°C and the panel is dipped for four seconds. Timing is done by means of an electronic timer which indicated the time cycles on red lights.

The rate of contamination of the solder in the baths is quite slow. A complete change of solder has only been found necessary over an eight-week cycle.

The Plated Circuit in the Large-Scale Production of Television Receivers †

by

W. I. FLACK ‡

A contribution given on 2nd July 1959 during the Institution's Convention in Cambridge.

Summary: The etched foil and plated techniques of producing printed wiring are compared. A detailed description is given of the plated circuit method. The advantages of the plated circuit are: greater reliability due to improved soldered connections to components, absence of curvature of the board, and ease of replacements of components.

1. Introduction

Printed wiring and printed circuits have been in use in all types of electrical and electronic equipment for many years, and have been accepted as a reliable and efficient feature of modern television receiver construction. It is not proposed in this paper to discuss the merits of printed circuitry in general, nor is it intended to compare the advantages or disadvantages with respect to the older, conventional methods of wiring: the paper will deal with a particular type of printed circuit, namely the "plated circuit." The words "printed circuits" are here used to denote the generic name of a process of mass producing electrical wiring and circuits by some means which includes printing as an essential feature of that process. Though circuit elements are not at present plated, there is nothing to prevent this from being done. So for convenience alone, the terms "printed circuits" and also "plated circuits," will be retained.

It is accepted that the printed circuit as we know it to-day, specifically the "etched foil" type, was invented some eighteen years ago by Dr. Paul Eisler[1, 2]. Mention of this fact is necessary to obviate confusion with another process, developed about the same time, by Sargrove[3], for mass production of electrical circuits, but this was done by the use of resin-bonded plates suitably moulded with recesses. The whole surface was then sprayed with metal, the raised portions subsequently having this metal ground off, leaving metal in the recesses only, which then functioned as conductors. At no stage was a printing process used and it is not relevant to include this process in a discussion on printed circuitry.

2. Etched Foil Circuits

The process for producing printed circuits, as devised by Eisler, is to bond to an insulated material, such as a phenolic laminate, a sheet of thin copper foil. A pattern of the desired conductor configuration is then printed onto the surface of the copper by either a silk screen or an off-set litho process, after which the panel is immersed in a suitable etching solution: those areas of copper foil not covered with printing ink are etched away, the remainder being protected from attack by the printed resist. After removal of the resist by means of a suitable solvent, a pattern of copper conductors remains on the surface of the insulated base material. This process whilst relatively simple has certain limitations, which will be dealt with later, but it is of particular interest to remember that the introduction of this new concept initiated research and development into alternative methods of producing printed circuitry. In these intervening years many methods of producing printed circuitry were developed but only one, the "plated circuit," has been in large scale production. Around 80-85 per cent. of all printed circuitry, both in Britain and in the U.S.A., is of the etched foil variety, the remaining 15 per cent. being of the plated type.

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† Manuscript first received 31st March 1959 (Contribution No. 25.)

‡ Radio & Allied Industries Ltd., Slough, Bucks.

U.D.C. No. 621.397.62

3. The Plated Circuit

Essentially, the plated circuit is an additive process, having the conductors plated on the base material rather than having the open areas etched away. The process necessary for plating the conductors is more involved, requiring appreciably greater plant and labour. The first stage in production is to pierce all holes, slots, etc., which will be required in the finished circuit. The insulated board, usually phenolic laminate of good quality, is then completely coated on both surfaces and through all holes with an adhesive lacquer. The function of this is to improve the adhesion of the conductors to the base material and at the same time to seal all cut and pierced edges, making the board virtually moisture-proof so as to maintain a high order of insulation resistance between conductors.

To electroplate on to an insulated surface, it is essential that it should first be made conductive and this is done by covering the surfaces and the inside of every hole with a layer of metallic silver. The application of silver as the conducting layer is convenient, since the silver may be chemically deposited from an aqueous solution, the process being largely based on that used in the mirror manufacturing industry. In the U.S.A. an alternative method of metallizing the surface has been in use for some time in which a layer of copper is deposited instead of silver. It is essential that the metallic coating should be homogeneous and have an adequate conductivity and current carrying capacity to carry the heavy plating currents which will subsequently be required.

At this stage, printing of the metallized surface is carried out, the printed pattern being the exact opposite of that required in the etched foil process, a negative image being printed. Those areas on which conductors are intended to be plated are left unprotected, the printed resist completely covering those areas which are required to be clear of metal and to be non-conductive. Since both sides of the boards have been metallized, it is only necessary to print the two sides to produce a double sided printed circuit and in fact virtually all plated circuits have conductors on both sides and through all holes. With both sides printed, it is only necessary for the boards to be suitably connected and placed into the copper electroplating baths for the copper conductors to be built up to an adequate thickness, usually not less than 0·002 in. To improve solderability and to obviate any deterioration of the copper conductors if stored for any length of time, solder plating may be carried out at the final electroplating stage, after which it is necessary to remove the printed resist, using solvents. The silver layer left uncovered is then removed by acid treatment or by an abrasive process. Then follows, washing, drying and finally curing of the adhesive lacquer, preferably under pressure, though this is not essential.

From this brief description, the greater complexity of the process will be appreciated. Nevertheless, in reviewing the features of any particular type of printed circuit, consideration must be given to the accompanying assembly techniques. The use of printed circuits is after all only a means to an end, the requirement being to increase the overall efficiency of production and to reduce costs.

4. Review of Assembly Techniques

Some two years ago the author's company undertook a comprehensive review of current production techniques, as a result of which it was decided to make use of printed circuits in the design and production of television receivers. The investigation was carried out in some detail both in this country and on visits to the U.S.A. and also by the study of the literature. In arriving at a decision as to the type of printed circuit to be adopted, consideration was largely given to the method of assembly which should be used so as to obtain the maximum benefits.

When making soldered joints in conventional wiring, it is normal practice that where possible a wire to be soldered to a contact tag, for example, should first either be wrapped around the tag or inserted through a hole or slot so that some simple mechanical joint is first achieved; the joint is finished by the normal hand soldering process using resin cored solder. Where a wire cannot first be attached mechanically, it is necessary to hold it in position whilst soldering, releasing it when the solder has cooled and set.

Nothing could be further removed from this technique than the type of soldering which is usual with printed circuits. In this, wire-ended components have their terminations pushed through holes in a panel and the panel is floated on a solder bath, or passed over a solder wave, the solder itself being expected to bridge the gap existing between the wire termination and the copper foil (Fig. 1). There is obviously no very simple or effective method whereby a mechanical connection of the type used in conventional wiring could be made and subsequently finished off with solder.

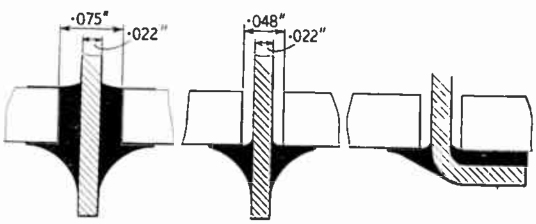


Fig. 1. Cross-sectional diagram showing 22 S.W.G. wire in etched foil and plated-through holes. All dimensions are in proportion and indicate the longer soldered joints obtained with plated-through holes.

It is at this point that we find many of the conflicting requirements which arise if the circuits are to be soldered consistently and reliably. Experience with etched foil circuits indicated that the greatest improvement in the reliability of the soldered connections would be achieved if the gap between the wire and the edge of the copper foil was reduced to a very small dimension. Yet, by making this gap very small, that is by making the hole diameter small, the difficulties in inserting the component termination wires into the panel were increased out of all proportion. Some few years ago, a standard hole diameter of 0·052 in. was laid down in the U.S.A. and many British manufacturers followed this lead thereby maintaining some degree of standardization which could have been, and probably was, of benefit when producing piercing and assembly machinery. The 0·052 in. hole was not however employed by all British manufacturers and hole diameters as small as 0·042 in. were also used.

There seemed little doubt that soldering efficiency and consequently reliability was enhanced by the smaller hole diameter since this gave a significant reduction in the clearance between copper and wire and permitted solder more readily to bridge the very small gap that remained. The use of the small diameter hole was not however regarded as being alone sufficient to overcome all soldering problems. Eventually, it became almost standard for the wire terminations to be bent or clinched, on the underside of the panel so that they were brought into closer contact with the copper areas. This "clinching" also had the advantage that the components were retained when the partially assembled panels were moved about or even turned upside down. Hand insertion of components combined with the cutting off of the existing wire length, and clinching, became a lengthy and a relatively expensive operation, though the method is still in use, particularly for small quantity production.

5. Mechanized Component Insertion

Machines designed for inserting components into printed panels had already been developed in the U.S.A. and were used by several of the larger American manufacturers. Perhaps the best known of these were the "in line" machines where a number of inserting heads were installed at given positions or stations, and a suitable transport mechanism used for transferring the panels. At each station, a single component was inserted into a panel, at the same time the wires being cropped to the required length and clinched beneath the panel. Anything from 20 to 40 wire-ended components were usually inserted into a single panel, depending on the number of inserting stations on the particular assembly conveyor.

A number of machines are in use in this country and their essential features and appearance are already well known.[4] It is sufficient to say here that the use of assembly machines of this type very largely overcame the disadvantages experienced when inserting and clinching components by hand. The machines also enabled the production of assembly panels to be increased rapidly without at the same time having to increase the assembly labour.

It is realized that new developments in printed circuitry and the accompanying production techniques are continuously taking place, and it would be dogmatic to believe that conditions which obtained some two to three years ago have remained unaltered. It is therefore likely that some of the difficulties which were experienced at one time may to some extent have been overcome; but in the main, conditions even now are not so different so far as etched foil circuitry is concerned from the conditions then known to exist.

From the foregoing, it would appear that if etched foil circuits are used and in this context the large scale production of television receivers only is considered, then it would be desirable to install mechanized assembly equipment. The installation of this equipment would require a very considerable capital outlay. One manufacturer of component inserting machinery was some three or four years ago quoting a figure approaching £1,000 per inserting station, though it is known that this figure has now been reduced to approximately £500 per inserting station, with a further £1,000 or £2,000 for feed-in and feed-out points. Even at this reduced cost, inserting equipment having 40 stations (and this is by no means a large number of components to insert) could not cost less than £25,000. It is believed that an installation of this type can now achieve an apparently favourable order of insertion reliability of probably around 99·9 per cent. Though a figure of 99·9 per cent. may appear to be high it can only be considered in the light of the total number of components which are inserted in a given time, for example 1,000 television receivers per day would require at least 200,000 components; with this quantity, assembly errors could become significant and under the worst conditions, could involve 20 per cent. of receiver production.

6. Etched Foil Circuits Assembly Requirements

We must assume therefore that the following conditions are desirable if etched foil printed circuits are to be used in the quantity production of television receivers:

(1) It is essential for reliable soldering to have a very small gap between the wire and the edge of the copper.

(2) It is desirable that the component terminating wires should be bent under the panel and clinched to improve soldering still further.

(3) Clinching of wires is desirable where small wire ended components are mechanically inserted, particularly if it becomes necessary to transfer the panels to another conveyor for insertion of the larger components such as valve holders, transformers, etc., and possibly to transfer once again for the dip soldering operation. If clinching is not done, then the small components will inevitably be shaken out of position.

(4) Because of the small holes and the desirability to clinch the wire terminations beneath the panel, mechanized assembly is desirable if a high production rate is required, particularly if this is to be expanded rapidly at short notice or if labour problems are likely to arise.

7. Features of Plated Circuitry Assembly Requirements

It is proposed now to give similar consideration to the production requirements for plated circuits. It may at first seem curious that the change to a different type of printed circuit, performing a similar function, should imply a fundamental change in the production technique, yet this may well be the case.

It is certain that the essential feature of the plated circuit which gives it such great advantages over other types is the fact that all the holes in a panel may be plated through so as to give a continuous conducting surface from the conductors on the underside of the panel to the conductors on the top of the panel. The elimination of jumper wires as such will be obvious and since now cross-overs can be made easily and readily, far greater use may be made of a jumper wire technique whereby conductors are permitted to cross each other wherever required by being taken from the bottom of the board through a hole, over the top, and through another hole back to the underside. One result of this is that the average length of conductor, particularly in heater and h.t. feed supplies is normally shorter than that in the equivalent etched foil circuit and furthermore conductors may be taken in a more direct line, between any two points on a panel. This can lead to a higher density of components than can normally be achieved with other types of circuit.

The economy in space thus gained could lead to a marked reduction in dimension.

The plated circuit enjoys yet a further benefit which brings it ahead of any other type of circuit. This again is due to the plated-through holes which lead to greatly improved efficiency of soldering. During dip soldering, the molten solder is caused to rise and fill each hole, being retained by surface tension even when the panel has left the soldering station. In this way a solid fillet of solder extends through the length of every hole and gives a long soldered joint which is both mechanically and electrically sound (Figs. 1 and 2). By the use of the plated-through holes, the amount of solder retained around the joints is substantial and because of this, it becomes possible very largely to increase the diameter of the holes. As a result of numerous experiments, and the extended use in production, the standard size of the smallest hole in plated circuits, is 0·078 in. which is at least 50 per cent. to 90 per cent. larger than holes normally considered standard in etched foil circuits. Because of the increased diameter holes, component insertion is improved and simplified and a rapid assembly of components may be achieved with few of the problems which could otherwise arise. Furthermore, as it is now possible to obtain the benefit of a long soldered joint and it is not essential to have the minimum clearance between wire and copper conductor, it does not become necessary to clinch the terminating wires on the underside of the panel; this is extremely important.

It will be seen then that the use of plated wiring with plated-through holes has immediately had two beneficial results:

(1) Hole diameters have been increased, making assembly appreciably easier.

(2) Soldering efficiency has been increased without the complications of mechanized insertion and clinching.

From the foregoing, it will be apparent that as it is only necessary to drop components into plated circuit boards, it is relatively easy to design an assembly conveyor in which all components, large and small, may be inserted without any subsequent transfer to other conveyors, and all soldered connections made. Empty panels can indeed be fed-in at one end of a

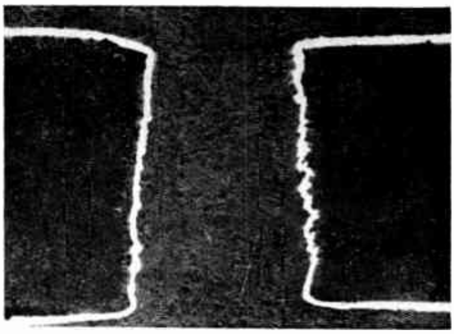


Fig. 2. Microphotograph of cross-section of plated-through hole.

conveyor and fully assembled and soldered panels removed from the other end. Because of these favourable factors, there is not the same necessity to employ mechanized insertion equipment, particularly as it is now easy to train new operators, the degree of skill required having been reduced. In the event of production requiring to be extended rapidly, little time need be lost in training further additional operators.

Summarizing, the essential features which were considered at that time when reviewing plated circuits, it can be stated:

(1) Plated circuits give stronger and more consistent and reliable soldered connections than do etched foil circuits.

(2) Due to the greatly increased size of holes, a high rate of manual insertion may be achieved and mechanized insertion machinery is not essential.

(3) A conveyor equipment may be designed on which all components can be inserted into the panels and soldering carried out without the panels having to be transferred to any other conveyor.

As a result of the conclusions drawn from this review, it was decided that plated circuits were the most suitable and the correct type of circuit for the requirements laid down. Before the final decision was made, consideration was given to the production problems inherent in the manufacture of circuits. It was realized that the manufacture of etched foil circuits was by far the easiest, requiring less labour, fewer stages of processing and an appreciably smaller and cheaper plant. Since, however, no commitments existed as to the use of etched foil circuits, the possibility was open to take a long term view, taking into consideration the manufacture of circuits over a number of years, rather than for one or two seasons only. It was known that, for example, the cost of plant to manufacture plated circuits would be at least four to five times that necessary to produce the same quantity of etched foil circuits, furthermore little or no experience in producing plated circuits was available and a considerable effort would be required in this direction since it would have to take in every single stage in production. With this outlook, and bearing in mind the relevant merits of the plated and the etched foil circuits, it was felt that the correct course was to adopt the plated circuit, making the required effort in development and the laying down of plant which it was realized would be necessary for the successful outcome of the project.

8. Development of Plated Circuit Process

Once this decision had been taken, the first step was to set up a Chemical Laboratory in which the development work would be carried out. This laboratory was fitted out with the usual glassware and instruments normally available in laboratories of this type, and there were also installed a complete scaled down plating equipment, various processing ovens, spray equipment for metallising, lacquering, etc., as well as printing machines. Although construction of the laboratory did not commence until September 1957 by the end of that year sufficient experience and knowledge of the processing had been obtained to give an appreciation of the size and type of production plant which was necessary. The Methods Department then designed the equipment which would be required both for the processing of circuits and the assembly of panels and receivers.

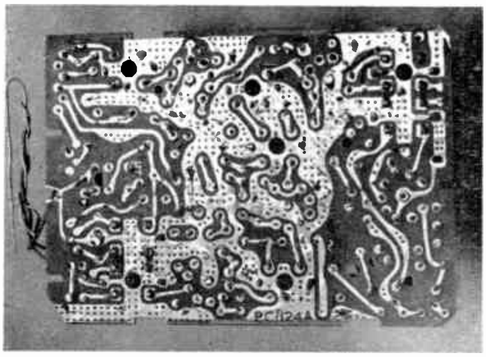
The first assembly conveyor was a shortened version on which experimental work could be carried out on the design of the transfer pallets, fluxing equipment, soldering equipment, etc., and the many other details to be settled if assembly was to flow smoothly. Advantage was taken of the availability of a proprietory wave soldering equipment which, after some modifications, was found to give a satisfactory performance. Work on the pallets was somewhat more involved than originally envisaged and was complicated by the fact that in supporting the panels it was essential that every part of the panel was free and unrestricted for the insertion of components. The panels were required to be held rigid and no movement or subsequent adjustment could be carried out until assembly was complete and they had passed over the fluxing and soldering stations. When a satisfactory performance had been achieved, a number of full length conveyors 50 or 60 feet in length were designed and put into operation.

Among the many separate but related developments which were carried out simultaneously, may be mentioned: the development and application of a silver conducting layer, the development and application of a suitable adhesive lacquer, a screen printing technique for working on plated circuitry, the electroplating of copper so as to give a thick malleable coating free from stress yet with good throwing powers to ensure effective plating though the holes, and the use of a tin/lead solder plate on the copper conductors to enhance the solderability of the circuits and overcome any possibility of corrosion.

Figure 3 shows a typical panel employing a plated circuit.

9. Advantages of Plated Circuits

As a result of this experience, certain additional virtues of plated circuitry have become apparent which more than ever have confirmed the author's belief in its superiority to other types of circuit. In the first place it has been noted that during processing as well as during assembly and soldering the circuits are invariably flatter and free from curvature distortion so frequently experienced with etched foil circuits. This flatness is brought about by the freedom from strains in the board itself, since plated conductors are applied to each side of the board, whereas the curvature experienced with etched foil circuits is usually caused by stresses occurring on one side of the board only due to the variation in the expansion coefficient of copper foil and phenolic board. It is not suggested that all etched foil circuits suffer from this distortion, but the tendency is present whereas with the plated circuits it is virtually



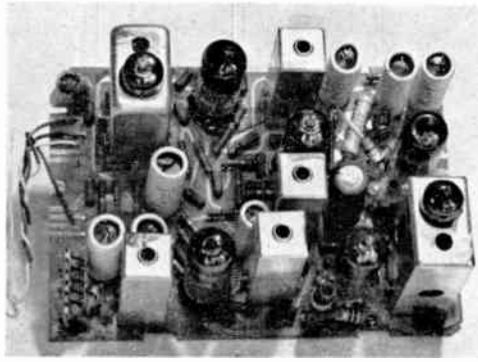


Fig. 3. Underside and top view of plated circuit i.f. amplifier.

absent. The benefits of a flat board cannot be overstressed, particularly in the maintenance of reliable soldering, since its flatness contributes so much to a constant depth of immersion during soldering.

Mention has already been made that the copper conductors on plated circuits may readily be solder plated and thus gives better solderability than any other method of surface preservation in general use on printed circuits. Even after an extended shelf life with few precautions to maintain the surface clean, conductors can be soldered with a smooth, even coat of solder over the whole area. The flow of solder is furthermore consistent whether the panels have been recently produced or may have been in stock for some time. This is very largely brought about by the fact that the solder plate is substantially a eutectic, being approximately 65 per cent. tin, 35 per cent. lead. There seems also a reduced tendency for copper from the conductors to be dissolved into the molten solder as the soldering temperature over an extended period can be held constant yet gives consistently smooth results. It has also been found that corrosion and oxidation of conductors is inhibited, the solder plate being effective in protecting the surface. Solder plating could of course be used with etched foil or indeed in other types of circuits but it is more economically and conveniently applied to plated circuits.

A further very important feature is shown up during repair when a component has failed and requires to be replaced. In unsoldering a component, whether a resistor, a capacitor or similar unit, it is only necessary to apply a soldering iron to the solder joint, melt the solder and remove the component. As the terminating wires are not bent or clinched beneath the panel in any way for mechanical retention, the operation may be achieved without difficulty. With the method of clinching so frequently used with etched foil circuits, it is necessary either to cut the component above the panel, connecting the replacement component to the wires of the previous component, or alternatively to melt the solder beneath the panel and by prodding in the pool of molten solder carefully to straighten the wire before withdrawing from the panel. Sufficient heat is normally required when melting the solder in these circumstances to risk the possibility of damage to the copper foil.

10. Conclusion and Acknowledgment

Experience during the past year with plated circuits has confirmed and justified the original assesment of their merits. So much so in fact that a fully automatic plant for board processing has been developed and will come into service in the near future.

Thanks are due to the directors of Radio and Allied Industries Ltd. for permission to prepare and read this paper.

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Printed Circuit Production for a Television Tuner †

by

P. C. GANDERTON ‡

A contribution given on 2nd July 1959 during the Institution's Convention in Cambridge.

Summary : The use of printed circuit techniques in the main chassis and coils of a turret tuner has lead to a far greater degree of consistency of production than with wired tuners. The method of preparing the basic etched circuit, its subsequent assembly, dip soldering and cleaning are described.

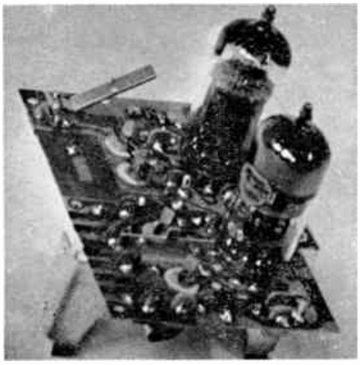
1. Introduction

At the beginning of 1959 the author's Company embarked on the manufacture of a printed circuit turret tuner in which the maximum possible use is made of printed circuit techniques to achieve consistency and economy in production (Fig. 1). Not only is the chassis printed, including the small inductance and capacitance values and parts of the trimmer capacitors, but also all the coils in the turret. These are produced to so great an accuracy that no alignment is required, even for the oscillator coils.

2. Circuit Requirements

The design of this unit shows an interesting combination of the electrical requirements with features necessary for ease of production. These will be discussed briefly.

Considerable attention was given to the design to reduce and control the tuner oscillator drift characteristics. A printed circuit laminate was devised in which the dielectric constants of both the adhesive and the base material have substantially zero temperature coefficients. Unfortunately, the material used is affected by all hydro-carbons and paraffins and therefore a method of processing had to be devised that did not require the use of these materials for cleaning. The "flow solder" system of soldering was considered to be the most satisfactory system. The design of the chassis was based on the use of wedge capacitors (Fig. 2) to achieve the degree of repeatability needed to use printed coils; to enable these to be used in a flow solder system, they have to be positioned so that they all lie in the same plane allowing them then to move through the bath edge-on to the wave.



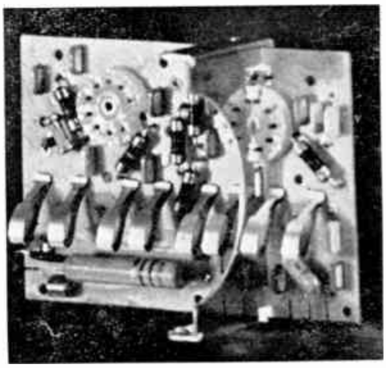


Fig. 1. Top and underside views of printed circuit tuner.

The necessity of earthing the copper to the metal chassis through short paths at discrete points, the use of printed stator plates for the trimmers, and close spacing of wires in printed

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‡ Sydney S. Bird & Sons Limited, Fleets Lane, Poole, Dorset.
U.D.C. No. 621.397.69

capacitors, necessitated selective soldering to ensure that all these areas remained clean and free of solder. The trimmers are shown in Fig. 3.

3. Printing and Soldering Techniques

To obtain the necessary definition for the printed coils and circuitry, the printing is based on a photographic method. The machinery is designed to handle boards of approximately 2 ft. square, the printing of these boards being done from a multi-negative with an appropriate number of impressions. The photo-resist used is water soluble to avoid the introduction of harmful chemicals on to the laminate. The board proceeds through the etching bath face downwards being fed between a series of rollers; ferric chloride etchant is paddle-splashed on to the under-surface of the board. The paddles are adjustable in their position and the whole machine is set up by running a board through somewhat faster than usual to produce a condition of just under-etching. In this condition it is easy to observe the uniformity of etch. Adjustments are made accordingly until the desired uniformity is achieved. The water-soluble resist is subsequently removed by the normal board washing process.

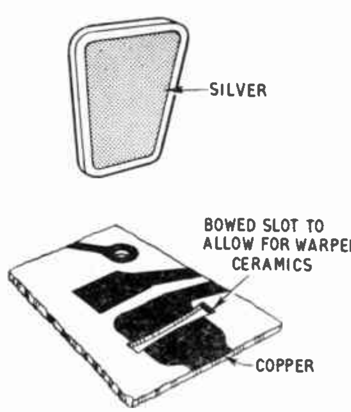


Fig. 2. Wedge capacitors.

After piercing, the boards are silk-screen printed with a water-soluble solder resist to confine the flow of solder to the points where it is required. The board is mounted in jigs which are designed to form the subsequent carrier through the solder bath; the necessary components are then hand-assembled on a conveyor line. Resistor leads are not crimped because dry joints are easier to detect with the leads vertical; if these leads are crimped over dry joints can be concealed.

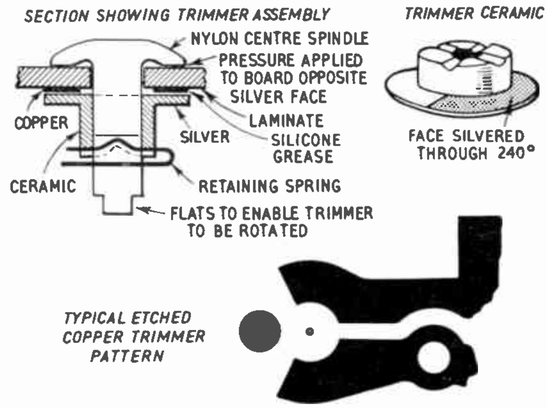


Fig. 3. Printed circuit trimmers.

The boards are first fluxed by passing over a weir. Next, the boards are pre-heated to avoid excessive thermal shock to the ceramic wedge capacitors which have to be soldered to directly. The solder bath contains 2 per cent. silver to avoid silver absorption off the face of the ceramics. The boards are subsequently cleaned of excessive flux by methylated spirits in an ultrasonic bath; the solder resist is also removed ultrasonically in water. At this stage the boards are assembled into a jig which electrically represents a completed tuner. They are aligned and tested on two channels to ensure that they function correctly before final assembly into the appropriate metal work.

4. Coil Production

The coil boards, which contain eight snap-in contact members, require to be soldered with considerable accuracy as any change in the amount or spread of the solder will vary the inductance beyond acceptable limits for the coil. This is also true of the machining of the coil with respect to its printing. The coils are produced on a high-grade, hot punching paper based laminate. Location holes are punched on the boards prior to printing, there being a hole at the head and end of each column of coils. From these holes the step and repeat negative is located. When machined, the board is first guillotined into columns and then fed on an indexing feed through the punch. Variations in punching mainly occur due to variations in temperature of the materials when being machined. The ambient temperature during printing is controlled to within 5°C, and the indexing feed is corrected to allow for expansion as the board is subsequently heated to 80°C for punching. It is impossible to control this temperature very accurately during its full feed through the tool, and punching errors therefore occur in the direction of the column, the boards being punched within 0·001 in. or 0·002 in. in a sideways direction. The coils are therefore designed so that the small conducting area of copper to which each contact is soldered runs along the side of this contact in the direction of the column. Connecting in this manner ensures that, even though the precise location of the punched hole relative to the copper may vary, the inductance will not subsequently change. The area of copper is such as to support completely the amount of solder used without any excess flowing back over the thin conductor. (See Fig. 4). Contacts are then fitted to these coils, the end of each one receiving a solder ring. These pass on a conveyor belt through an r.f. soldering position, the result being an accurate uniform amount of solder contained in a specific area.

To counteract the effects of humidity on the copper-clad laminates, after processing and assembly, both coils and chassis are dried and

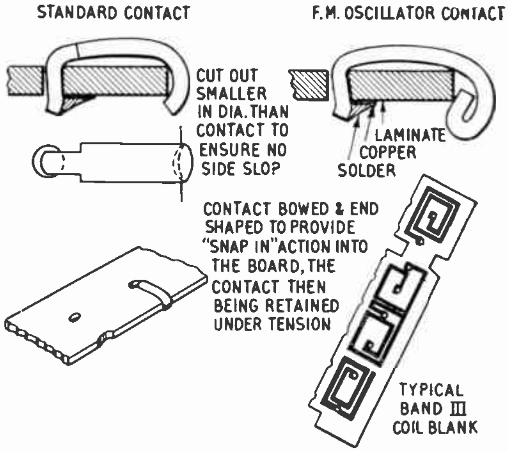


Fig. 4. Coil board arrangement.

impregnated with silicone oil of 100 centistokes viscosity. They are centrifuged to remove the excess fluid, leaving a residual film over the surface of all components.

5. Conclusions

The applications of printed circuits and associated techniques in this unit has lead to a higher standard of production, more consistent results, and a lower cost than would have ever been possible in conventional wiring and wound coil techniques. The spread in gain on these tuners is on average, under half that experienced on wired tuners. Frequency stability shows the same degree of improvement.

FURTHER DEVELOPMENTS IN PRINTED CIRCUIT AND COIL ETCHING

A continuous plant for the spray etching of printed wiring and components has been developed which is essentially a continuous conveyor system through which the printed boards pass to meet a spray of etching fluid, followed by washing sprays, and are then dried.

The basic design, which calls for construction in corrosion resistant structural plastic materials, consists of a tunnel-shaped etching chamber located on the top of an etchant-holding tank. The etchant is drawn from the holding tank by means of a vertical glandless pump and passed to a system of horizontal spray assemblies from which atomized sprays of etchant are projected onto the boards. The etchant having been sprayed on to the boards then falls to the base of the etching chamber from which it flows by gravity back to the holding tank through a filter system.

The plant has been designed by the Kestner Evaporator and Engineering Co. Ltd., for the works of Sydney S. Bird & Sons Ltd.

The Technical Consideration of Television in the International Field †

by

T. KILVINGTON, B.SC.ENG. ‡

An address given on 1st July 1959 during the Institution's Convention in Cambridge.

Summary: International aspects of all classes of telecommunications are dealt with by the I.T.U. (International Telecommunications Union) and its consultative committees, the C.C.I.R. (radio) and C.C.I.T.T. (telegraph and telephone). Over the past few years considerable discussions have taken place in these bodies on the standards for television and particularly on the requirements for the point-to-point transmission of television signals over long distances. A recommendation on the latter subject has recently been adopted by the C.C.I.R. and forms a useful basis for the design of microwave and coaxial-cable television relay links.

1. The C.C.I.R.

The letters C.C.I.R. are probably familiar to the majority of radio engineers but it is unlikely that very many of them know exactly what they stand for and how the organization to which they refer operates. This brief address will first of all discuss the C.C.I.R. itself and then describe some of the aspects of television which have concerned it for a number of years.

The letters C.C.I.R. stand, in French, for Comité Consultatif Internationale Radio or, in English, with some small changes and an alteration in the word order—International Radio Consultative Committee.§ This is one of the two consultative committees which advise the International Telecommunications Union on technical matters, the other being the C.C.I.T.T. (International Telegraph and Telephone Consultative Committee). The International Telecommunications Union (I.T.U.) is one of the specialized agencies of the Universal Nations, some others being the Universal Postal Union, the World Meteorological Organization, the International Civil Aviation Organization, and the International Scientific Radio Union.

The International Telecommunications Union has the task of formulating regulations relating to all those aspects of telecommunications that require international agreement. To this end it relies upon the technical advice of its two consultative committees. Each committee has a permanent director and secretarial staff located at Geneva but the main technical work is carried out by experts from the different member countries.

For convenience the radio field is divided up into fourteen sections each of which is dealt with by a Study Group working under an International Chairman and Vice-Chairman. The Study Groups carry out their work partly by correspondence, partly by interim meetings and partly by meetings held during the course of Plenary Assemblies of the C.C.I.R. These Plenary Assemblies are held at intervals of approximately three years, the latest taking place at Los Angeles in April of this year. The three previous meetings were held in Warsaw (1956), London (1953) and Geneva (1951).

The basis for the work of each Study Group is laid down in a series of *Questions* which require answers, and *Study Programmes* designed to lead towards these answers. When the answer to a question is wholly or partially agreed upon, a *Recommendation* is formulated but if the study is incomplete then a *Report* on the progress of the work may be drafted. Finally, if, arising out of its technical considerations, it appears that some administrative action might be desirable such advice is incorporated

† Manuscript received 12th November 1959. (Address No. 20.)

‡ Post Office Engineering Department, Research Station, Dollis Hill, London, N.W.2.

U.D.C. No. 621.397:341.16

§ See also R. L. Smith-Rose, "International radio organizations—some aspects of their work," *J. Brit.I.R.E.*, **18**, pp. 631-639, November 1958 (Sections 5 and 6).

in a *Resolution*. The drafts of all these documents, prepared by the Study Groups are considered by the Plenary Assembly, discussed, amended if necessary and adopted, or in a few rare cases, rejected. The recommendations of the C.C.I.R. are not in themselves mandatory but in their own interests, member countries generally abide by them and often use them as a basis for equipment specifications. For this reason it is an advantage for manufacturers to be able to show that their equipment conforms to C.C.I.R. (or C.C.I.T.T.) standards. Some of the more internationally important recommendations form the basis for radio regulations of the I.T.U. to the observance of which most countries bind themselves.

2. Television Standards

The Study Group concerned with Television is No. XI and it has for some years been studying among other things the question of television standards and the requirements for the transmission of television signals over long distances. On the question of standards there is an impression existing very widely that there is a C.C.I.R. standard for television signals. There are constant references in the technical press to the "C.C.I.R. 625-line system." Such references are incorrect. In 1950 when the question of a single standard for monochrome television was under discussion it was not possible for complete agreement to be reached and the best that could be achieved was a very general recommendation on certain features of a television signal such as: aspect ratio, interlace ratio, scanning sequence, vestigial sideband operation, stabilization of black level, etc., with which all of the existing systems comply. Further than this the C.C.I.R. could do no more than record the characteristics of the systems in use in the form of a Report, in the hope that any countries newly establishing a television service would use one of the existing standards. This is still the position to-day and the C.C.I.R. documents contain details of seven different "standards."

3. Long-Distance Transmission

The requirements for the long-distance transmission of television signals have been under discussion since about 1951. Prior to that time a number of long distance links had been set up in the United Kingdom which were to some extent experimental and gave the best possible performance with the then known techniques, without worrying too much as to how these links would fit into a very much longer transmission circuit. With the setting up of television services in a number of European countries however, the desire to exchange programmes naturally followed. In some cases circuits of considerable length, passing through a number of different countries, were involved so that the need for international agreement on the required transmission characteristics for these circuits is apparent.†

The British specification for the transmission of 405-line signals was submitted at the Geneva Plenary Assembly in 1951 and formed the basis for much of the discussion that followed. Up to 1956 separate discussions on the problems were proceeding in both the C.C.I.R. and the C.C.I.T.T. The overall requirements for video-to-video transmission are clearly the same, as far as the user is concerned, no matter whether the intervening link is by cable or radio. Consequently, at its Plenary Assembly in Warsaw in 1956, the C.C.I.R. approved, by means of a Resolution, the setting up of a joint C.C.I.R.-C.C.I.T.T. Study Group representing both the cable and radio interests, to prepare an agreed specification. This body, known as the C.M.T.T. (Comité Mixte des Transmissions Télévisuelles) has held two meetings and drafted a Recommendation. This was adopted by the C.C.I.R. at Los Angeles and it will most likely be adopted by the C.C.I.T.T. at its next Plenary Assembly.

4. Hypothetical Reference Circuit

The performance of a transmission circuit must clearly depend upon its length and make-up. As a basis for specification therefore it is necessary to adopt some standard—in this case "the hypothetical reference circuit." Since the "hypothetical reference circuit" is to provide a basis for the planning and design of transmission systems it should have a length which is reasonably but not excessively long and, in the case of a television circuit, a defined number

† See, for example, H. Mumford, "Some aspects of television transmission over long distance cable links," *J. Brit.I.R.E.*, **19**, pp. 509-519, August 1959 (Section 2).

of video-to-video sections. The length chosen is 2,500 km (about 1,600 miles) and it is assumed that two video points divide the circuit into three sections of equal length. It is also assumed that the three video-to-video sections are lined up individually and then connected together without overall adjustment and that the circuit contains no standards converter or synchronizing pulse regenerator. It is appreciated that at the present time an international television circuit of 2,500 km length is likely to contain more than three video-to-video links in tandem but it is hoped that the number will be reduced in time and three is regarded as a desirable target.

If a circuit is longer than 2,500 km or if it contains more than three modulation/demodulation processes the performance may be expected to be lower than that recommended. Also the long-distance transmission path is not the only source of distortion in the overall system—allowance must be made for the picture generating equipment, the shorter national links used at each end of the long-distance circuit, and the broadcasting transmitter and the viewer's receiver. For these reasons the performance specified for the hypothetical reference circuit is one which, by itself would cause very little perceptible impairment of the picture. Having defined such a circuit and specified its performance, it remains for the equipment designer to divide up the permitted distortions and apportion them between the modulating equipment and the transmission equipment, the share for the latter being adjusted in accordance with the length of the circuit being considered.

5. Recommendations

The items specified in the new C.C.I.R. Recommendation may be divided into two broad classes. First there are those parameters that apply at any video point and are not affected by the length of the circuit. These include the impedance of input and output circuits and the amplitude, polarity and form of the video signal. Thus an impedance of 75 ohms is generally recommended. The video signal, as illustrated in Fig. 1, should have a nominal amplitude of one volt peak-to-peak, 70 per cent. picture signal and 30 per cent. synchronizing pulse and should have positive polarity, i.e. black-to-white transitions should be positive-going.

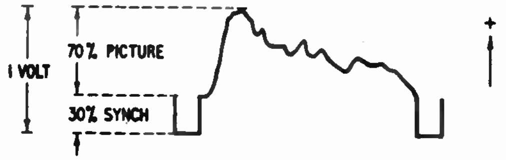


Fig. 1. Form of signal at a video point.

The second group of characteristics are those which do depend upon the length of the circuit under consideration. These include gain, signal/noise ratio, non-linearity, linear waveform distortion and the steady-state characteristics. Thus the insertion gain of the 2,500 km circuit is specified to remain within the limits ± 1 db.

Noise is a complex subject and the specification covers not only random noise but also periodic interference. The subjective effect of random noise on a picture depends upon the energy distribution of the noise within the video band. Thus triangular noise, characteristic of frequency modulation systems is less obtrusive than white noise produced in amplitude modulation systems. These and other noise energy distributions can be catered for by measuring the noise through a suitable weighting network, that for the 405-lines system being shown in Fig. 2. Similar networks for the different systems are specified together with the permissible signal/weighted-noise ratio. It should be noted that in expressing this ratio the picture amplitude is taken as the peak-to-peak voltage of the picture part of the signal, excluding the synchronizing pulses, and the weighted noise is measured by its r.m.s. voltage. For periodic interference the subjective effect decreases with increasing frequency of the interference above about 1 Mc/s and appropriate limits, suitably graded, are given.

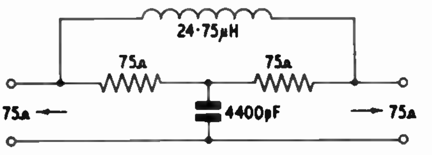


Fig. 2. Weighting network for noise in the 405-line system.

Non-linearity is also a very complex question and is not yet fully covered. Its effect on the picture depends upon the time scale examined. Thus switching suddenly from one picture to another with a substantially different d.c. component can cause a transient non-linearity which takes an appreciable time to disappear. This is called "field-time non-linearity" and no limits for it are yet specified. Then there is the more usual type of non-linearity giving rise to general distortion of the large-area half-tones in a picture—known as "line-time non-linearity." A method of test and limits for this defect are given in the Recommendation.

Finally, there is "short-time non-linearity" which affects the picture detail contrast without affecting the large area contrast appreciably. The method of test and limits for this have not yet been agreed. A further important aspect of non-linearity in transmission is its effect on the synchronizing pulse amplitude and this is fully covered.

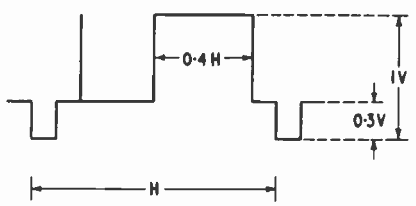


Fig. 3. Pulse-and-bar test signal used in the U.K.

Linear waveform distortion too can be divided according to the time scale into "field-time" "line-time" and "short-time" distortion and test methods and limits for all these have been specified. The pulse-and-bar signal used in this country is illustrated in Fig. 3.† Whereas in the early days steady state characteristics were used to specify the transmission response of television circuits, nowadays, thanks largely to pioneering efforts in this country, these methods have been almost wholly abandoned in favour of waveform specifications. This is logical since fidelity of waveform transmission is the essential requirement from a television transmission circuit. Furthermore, it is not possible to set reasonable limits for the steady state characteristics which will ensure the attainment of a given waveform transmission response. The sine-squared pulse used in this country for "short-time" testing has not yet received full acceptance as the test signal for all the systems probably due to lack of experience with this test method in other countries. It may well be that in the future as more experience is gained the sine-squared pulse will be universally adopted.

† I. F. Macdiarmid, "Waveform distortion in television links," *J. Brit.I.R.E.*, **20**, pp. 201-216, March 1960.

6. Conclusion

C.C.I.R. recommendations are not static. As techniques evolve, so they must be brought up-to-date, often with increased stringency in the requirements. In this particular field of television point-to-point transmission there is still work to be done and some of the gaps in the existing recommendation have been pointed out; in addition a better understanding is required of the way that distortions add up in links connected in tandem. This will enable the tolerances to be divided up between the component parts of a circuit with greater confidence. Finally there is the extension of the field to cover the requirements for the transmission of colour television signals. This is a study that can only be undertaken when a colour system is decided upon and it is likely that it will indicate a need for still better transmission characteristics.

7. Acknowledgment

I am indebted to the Engineer-in-Chief of the Post Office for permission to deliver this address.

News from the Sections . . .

West Midlands Section

The paper given before the Section in Wolverhampton on 10th February by Mr. I. W. Merry was on "Electronic Reading." It took the form of a survey of the problems encountered in automatic character recognition and of the techniques employed to overcome these problems with special reference to ERA (Electronic Reading Automaton).

Mr. Merry opened by saying that in undertaking the design of a system the major considerations were the scope of what it was required to read, the speed of operation and the accuracy of recognition.

At present the general trend in development was towards machines which covered a comparatively narrow field of pattern recognition with maximum reliability and handling speed, at a price which their commercial use could justify. Unfortunately, characters of ample density and clarity of form for human interpretation had often a very poor contrast with their background, from the machine's point of view. Two general approaches to the problem had been made, one involving recognition of information printed in magnetic ink, the other accepting normal printing and using optical methods.

The Solartron ERA employs this latter technique and is capable of recognizing about 250 characters per second with extremely high accuracy and only requiring a moderate standard of print definition. The character to be read is scanned by the master traced out by a flying spot c.r. tube, reflected light being picked up by a photomultiplier. This information, in pulse form, is fed into matrix stores, each cell corresponding to a particular reference on the raster. Logical circuitry is then arranged to scan the matrix and make recognition decisions for which it has been programmed, these determining the machine's output. In its present form, 21 different numerals and characters can be recognized, the output information being coded for direct feed into a computer.

In conclusion, Mr. Merry discussed the relation between the number of characters which a machine could be programmed to accept, and the quality of character definition. Obviously, if the form and relative position of all characters was perfectly designed, recognition was much easier, as ambiguities could be avoided with less complex logical circuitry. This latter problem, apart from its influence on current machines, represented the major difficulty to be faced by designers of machines to accept handwritten characters.

F. D.

South Midlands Section

Over 50 members and visitors assembled in the North Gloucestershire Technical College at Cheltenham on 4th March for the 25th meeting of the Section to hear Mr. K. Fearnside, M.A., Director of Research and Engineering of Smith's Aircraft Instruments present his paper on "The Use of Radio Aids in the Control of Modern Transport Aircraft."

Mr. Fearnside gave a brief outline of the history of the links between radio and aviation from 1930 onwards. He then described the present v.h.f. omnirange (VOR) navigation system. This operates at about 100 Mc/s, and employs phase comparison between a carrier and a sub-carrier to give the required bearing information. The VOR system enables an autopilot to control the flight of an aircraft on any set course from or to a transmitting beacon, either along a radial from the beacon or with a given course deviation. The author then dealt briefly with systems which incorporate range as well as bearing information. Doppler systems giving accurate ground speed and drift angles were mentioned.

The second half of the paper was devoted to instrument landing systems. The present I.L.S. approach aid gives automatic approach down to 200 ft after which point the human pilot takes over for the final run in, and developments for civil use of a safe and fully automatic landing system based on one which already meets military requirements were described. In this technique leader cables carrying low frequency currents along each side of the runway are used for the final glide path.

During the discussion Mr. Fearnside quoted a fault rate in aircraft of better than one failure in 180 flying hours, and accounted for this low figure by the wide use made of magnetic amplifiers. Other matters raised included GCA landing, the maximum deviation of an aircraft from the correct glide path, automatic acquisition of the glide path, and what happened if the glide path was missed. On points of radio engineering practice other members sought information on the matching of transmitting aerials and reasons for using vertical rather than horizontal polarization in the VOR system. Inevitably the cost of the various systems was raised.

A. H. M.

North Western Section

At a meeting held on the 4th February, Mr. E. S. Benson, M.B.E., M.A., F.R.I.B.A., read a paper on "Acoustics in Modern Buildings." He introduced the subject as a relatively new one and emphasized the double nature of the problem. It was firstly one of sound insulation —now becoming acute by reason of the large amount of noise produced in modern cities, coupled with the new and lighter building methods—and, secondly, of providing good listening conditions in auditoria.

The problems with auditoria could be summed up as:

(1) The complex nature of musical sound and the need to maintain this complex character in reflected sound,

(2) The apparent lack of volume in enclosed spaces with absorbent furnishings necessitating adequate reflecting surfaces and,

(3) The relatively slow speed of sound and the consequent liability to produce echoes by reflected sound in large halls.

After this introduction the effect of the shape of the auditorium was fully discussed and the use which could be made of walls, floor and ceiling surfaces to obtain even and adequate distribution of the sound was described.

The importance of correct reverberation times for both speech and music was then discussed and Mr. Benson showed how the basic formulae had been built up by the analysis of halls of known quality. He then illustrated the methods by which the characteristics of a hall could be corrected at different frequencies and the various problems involved in designing halls for different users, e.g. theatres, concert halls, halls for debate, and so on.

The final part of the lecture was devoted to a description of the problems of sound insulation in modern urban buildings.

A field of research into which electronic techniques have recently been introduced with considerable success was the subject of the Section's meeting on 3rd March when a most interesting lecture on "Electronic Techniques in Oceanography" was given by Mr. M. J. Tucker. Mr. Tucker, who is a leading worker in this field, is with the National Institute of Oceanography.

To introduce his subject, Mr. Tucker first explained the general factors which govern the design of electronic equipment for oceanographic use and the design of housings for withstanding high sea pressures. The differences in the properties of radio and acoustic waves were illustrated by comparison of a typical radar and its acoustic equivalent. Some interesting analogies were drawn and underwater acoustics was discussed in some detail from the aspect of its use for echo-ranging and detection, telemetering, etc. The question of reliability of instruments and the necessity for fixed sensitivity were stressed.

An acoustic telemetering device, which is used extensively at the present time, called a "pinger" was then described. In its simplest form, a capacitor is charged from hearing aid type batteries and discharged through a cold-cathode, gas-filled tube, in series with the winding of a "scroll" type magneto-striction transducer. A damped train of waves is thereby emitted at its natural frequency in the region of 10 kc/s. The use of the "pinger" for measuring deep ocean currents, its attachment to a deep-sea camera and other useful applications were explained. A f.m. pressure gauge wave recorder having a resolution of one part in a million of full scale and which is suitable for digital recording and analysis was also described.

F. J. G. P.

[*Editor's note*: Mr. Tucker's paper is to be presented at an Institution meeting in London on 27th April].

Some New Possibilities in Civil Underwater Echo-Ranging †

by

Professor D. G. TUCKER, D.SC., MEMBER ‡

A paper read on 6th January 1960 at a meeting of the Radar and Navigational Aids Group.

In the chair: Mr. F. G. Diver, M.B.E. (*Member*).

Summary: The paper describes eight projects currently in hand in the Electrical Engineering Department of the University of Birmingham; these are essentially practical projects, leading more or less directly to substantial improvements in echo-ranging techniques for fisheries operations and research, navigation, surveying and general oceanographical work. The projects are: electronic sector scanning, multiplicative reception, wideband echo-ranging, interferometric echo-sounder, "bottom-lock" frequency-modulated echo-sounder, continuous-wave echo systems, transfer of oscilloscope display to paper chart, and automatic electronic beam stabilization.

1. Introduction

The Electrical Engineering Department at the University of Birmingham has for some years included underwater echo-ranging systems among its topics of research, and an account is given here of eight projects which are currently in hand and are of the type which lead to immediate applications in fisheries operations and research, in navigation, surveying and oceanography generally. It will, of course, be appreciated that these practical projects are largely the outcome of, and are also supported by, a considerable amount of theoretical and more academic investigation which will not be discussed here, but which has already led to the publication of over a dozen papers—several in this *Journal*. In a different sense, the work has also received support from other organizations—financial assistance and/or encouragement and co-operation from the National Institute of Oceanography, the Fisheries Laboratories at Lowestoft (Ministry of Agriculture, Fisheries and Food), the Marine Laboratories at Aberdeen (Scottish Home Department), and the Admiralty. The continued help of N.I.O. in providing facilities for sea-trials on R.R.S. *Discovery II* is of particular value.

It will be obvious that the work described here is due only in part to the author. Major contributions to it have been made by Dr. V. G. Welsby, Mr. L. Kay, Dr. J. W. R. Griffiths and Dr. E. A. Howson of the staff of the Department, and by the following present or former research students: Messrs. R. Kendell, A. Chatterjea, E. Hands, B. K. Gazey, G. D. Sunderland, B. McCartney, J. R. Dunn, J. Zaidman and J. C. Morris.

2. Electronic Sector-Scanning

As the basic principles of the electronic sector-scanning asdic, the design of an experimental system, and its first trials on R.R.S. *Discovery II* in October 1958 have already been published in this *Journal*[1, 2], there is no need to describe its details here. It will suffice to observe that the bearing scan is so rapid that it is completed within the duration of the pulse and is immediately repeated; thus no information is lost, and all directions in the sector are effectively looked at simultaneously, but with the angular resolution corresponding to the beamwidth of the receiving transducer.

The experimental equipment which has been described in a previous paper[2] had a scanned

† Manuscript received 14th January 1960. (Paper No. 553.)

‡ Electrical Engineering Department, University of Birmingham.

U.D.C. No. 623.983 : 639.2.081.7 : 621.396.96

sector covering eight times the receiving beam-width, which was 1·5 deg; the pulse duration was 1 millisec, the scanning rate 1000 sectors/sec, and the acoustic frequency was 37 kc/s. It was shown to be able to give good pictures of fish shoals both with the beam nearly horizontal, and also with it vertical. Thus the distribution of fish (and other objects) within a volume of sea can be quickly determined, and there is no risk of losing information in the way that ordinary single-beam asdics and echo-sounders do, due to their very slow speed of search. When it is realized that the velocity of sound in water is only about 1 mile/sec, it can easily be seen how slow a search with a single-beam system must be.

In addition to its obvious use as a fish locator, as a navigational aid (with horizontal or vertical beam) and as a hydrographic surveying instrument, the system can be of considerable value as a tool in fisheries research. For this reason, the experimental equipment was fitted once again in R.R.S. *Discovery II* for a 3-week trial in November 1959, in which biologists of the Fisheries Laboratories at Lowestoft hoped to gain some new information about the migration of fish. It proved possible to observe the direction in which small shoals of fish moved in relation to the tidal currents (those observed swam in the direction of the tide), and it seemed that a long-standing biological question had at last been answered, and a new line of research indicated on the orientation mechanisms of the fish.

Trials of the equipment as a vertical-beam surveying instrument were held, also in R.R.S. *Discovery II*, during December 1959 in the Atlantic, and, in spite of very poor sea conditions, good displays of the slopes at the edge of the Continental Shelf were obtained, as illustrated in Fig. 1. It is interesting that the sector display remained effective, in spite of "quenching" by aeration, long after the chemical recorder systems had failed.

Current engineering research is directed towards understanding the factors which limit the speed of scan. New requirements which the marine biologists now put forward indicate that a very narrow receiving beam and very short pulse are desirable so that individual fish can be observed, the shape of trawl nets followed, etc. A sector width of 17 deg with resolution of 0·5 deg, together with a 0·1 millisec pulse and 10,000 scans/sec, and with detection up to a few hundred feet will be the order of performance necessary, and this appears to be very near the theoretical limits of the system. A preliminary discussion of the way in which the time delays in the delay line cause distortion of the scanned signal was given in the first paper[1] on the system; the latest theoretical studies include the effect of scanning the beam across the sector more than once per pulse duration while

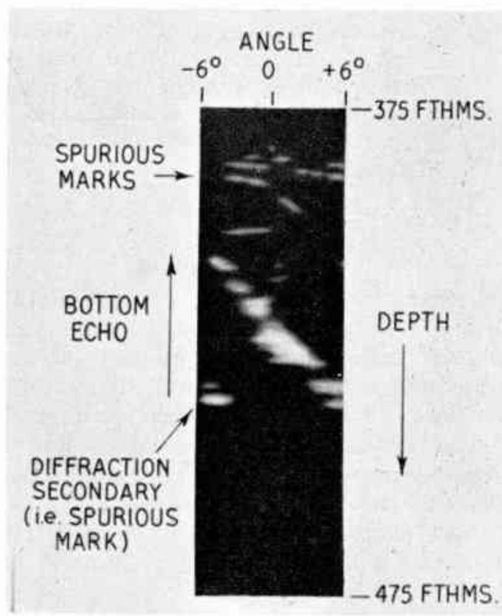


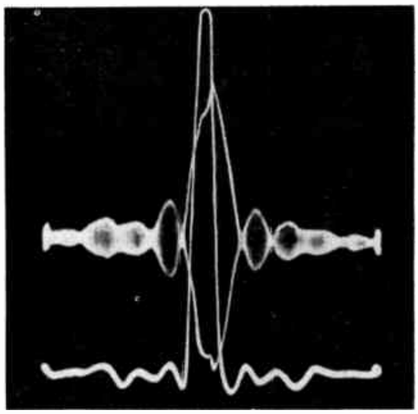
Fig. 1. Sea-bottom profile on display of electronic sector-scanning echo-sounder.
(Atlantic, slopes of Continental Shelf, approx. 47°30′N. 7°15′W, 12th Dec., 1959).
(Courtesy *International Hydrographic Review*.)

permitting the extent of distortion on each scan to exceed that which would be acceptable on a single scan per pulse duration. Experimental checks on this work will soon be made. If they confirm the theory, a high-resolution sector-scanning asdic will be designed and constructed.

3. Multiplicative Reception

A theoretical study of the performance of a multiplicative receiving system with a relatively narrow frequency band has already been published[3] in this Journal. The conclusions reached were that directional effects have to be considered more carefully than with ordinary linear additive arrays, since when the outputs of two parts of an array are *multiplied* together, the directional response to a single source is not an indication of signal/noise discrimination. The angular accuracy of location of a source (or target, if echo-ranging) is twice that of the same array used additively, but the signal/noise discrimination, and the discrimination against interfering signals simultaneously present, are at least 3 db worse. Therefore it cannot be determined whether a multiplicative system is better or worse than an additive system without reference to its specific application. It is clear, however, that there are applications where the increased angular accuracy is important. Moreover, the output signal from the multiplier is a d.c. (for a steady input signal from a fixed direction), and alternate lobes of the directional pattern are of negative polarity and so may be removed by a rectifier. The resulting directional pattern may therefore be very good indeed, and far better than can be achieved by any readily realizable super-directive array[4]. It must be emphasized that this discussion refers entirely to narrow-frequency-band systems.

The previous paper[3] showed the calculated directional response (i.e. the output voltage plotted against the direction from which a single signal is received) of a multiplicative array divided into halves, the outputs from two equal sections being multiplied together. The first secondary lobes are admittedly large, but when these are removed with a rectifier there remain only comparatively small secondary responses. Experimental work has been carried out at the Department's underwater laboratory at a Staffordshire reservoir to check the theoretical work, and measured multiplicative responses agree well with those calculated, for a range of conditions. Figure 2 shows an interesting comparison of additive and multiplicative responses for the same nine-section array. The directional patterns are plotted on a cathode-ray tube as the array is swung at a steady angular velocity while receiving a 50-kc/s signal from a point transmitter some hundreds of feet distant. The additive response shows the envelope of the 50-kc/s signal, and the phase is reversed in alternate lobes. The multiplicative response is that obtained by multiplying the output from one group of four sections with that from the other group of five sections of the array, and outputs of negative polarity have been removed by a rectifier. It can be seen how the multiplicative response has a main lobe of half the width of that of the additive response, and has also much smaller secondaries.



(a)

(b)

Fig. 2. Comparison of measured directional responses of a 9-element array.
(a) normal additive pattern (some phase errors are apparent, however).
(b) multiplicative pattern after passing through rectifier (output of 4 elements multiplied by that of 5 elements, then smoothed).

Signal/noise measurements, and the application of multiplicative reception to the electronic sector-scanning system, are currently in hand.

4. Wideband Echo-Ranging

Normally echo-ranging systems have a relatively narrow frequency bandwidth—only a small fraction of the centre frequency. Widening the bandwidth of an ordinary system, whether of pulse or frequency-modulation type, improves the detection of an echo which is weak compared with the noise and reverberation background[5]; but in all systems of this type, the bandwidth still remains a fraction of the centre frequency. Research in hand at Birmingham is directed towards an echo-ranging system where the bandwidth may have a ratio of upper to lower frequency of ten or more. Such a system may reasonably be termed "wideband".

The object of this wideband system is to obtain information, not only about the range and bearing of an underwater object, but also about its frequency response. Fish, for instance, are known to have a target strength (or equivalent echoing cross-section) which is a function of frequency[6], the peak of response presumably occurring at the frequency of resonance of their swim-bladders. This frequency response is markedly different for different species, and so it provides a means of identification in addition to detection and location.

There are many problems to be solved in developing such a system, and work is in hand on some of them; but the first to be tackled was that of obtaining a directional receiver. This is not straightforward, since an ordinary transducer has a beamwidth approximately inversely proportional to frequency. A beamwidth which varied with frequency would, however, be relatively useless in the echo-ranging system proposed, since an observed frequency response would have to be corrected for the angular position of the target in the beam—if this could be ascertained ! Yet an omnidirectional receiver would not permit location of the target, and the absence of directional discrimination might prevent its detection. It is therefore necessary to have a receiving array which has a beamwidth approximately constant over the frequency range concerned.

There is more than one way of achieving this result. The method developed at Birmingham[7] is to have an array divided into sections, which are connected, via decoupling circuits, into a number of delay lines, as shown in Fig. 3. These delay lines have a phase-shift which increases with frequency, so that at each end the effective directional pattern is deflected by an amount which increases with frequency. Successive delay lines have a successively larger range of phase-shift. Then, after correcting the phase of the outputs from the various lines so that they are all in the same phase whatever the frequency, the outputs are all added together. Now at the lowest frequency of the range, the phase-shifts in the lines are small (ideally zero) and the directional patterns all very nearly coincident; their addition therefore produces only the ordinary (sin x)/x pattern

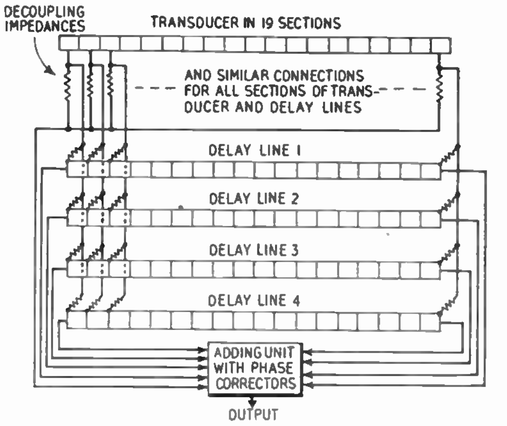


Fig. 3. Schematic diagram of constant-beamwidth wideband array.

corresponding to the number of wavelengths in the length of the array at that frequency. As the frequency is increased, the individual patterns at the delay-line outputs begin to separate, so that their addition leads to a wider beam in terms of wavelength—but it is arranged that the beamwidth in terms of physical angles remains very nearly constant; about ±10% variation over a 9-to-1 frequency range is the best obtainable. Figure 4 shows the state of affairs at the maximum frequency. Above this frequency, dips occur and the pattern begins to break up.

In this system it will be difficult to operate the transducers at good sensitivity, as resonance frequencies have to be avoided; but where

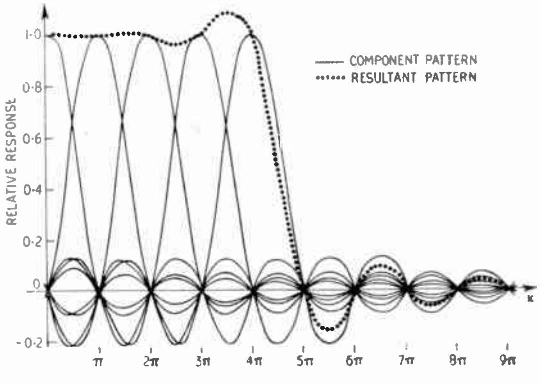


Fig. 4. Right-hand half of beam pattern for arrangement of Fig. 3 at upper frequency limit.

detection is limited (as it usually is) by noise and interfering signals in the sea, this will not matter. An experimental array covering the frequency range 9-81 kc/s has been built and is awaiting trials at the reservoir laboratory.

5. Interferometric Echo-Sounder

In bathymetric surveying, difficulties arise when a normal widebeam echo-sounder is used above a sloping sea-bottom—one cannot tell where the echo is coming from—but highly-directional systems also give difficulty since the echo received from non-normal incidence may be very weak. Work at Birmingham leads to two solutions of this problem; one is the electronic sector-scanning system discussed in Section 2, and the other is the interferometric system[11] now to be described.

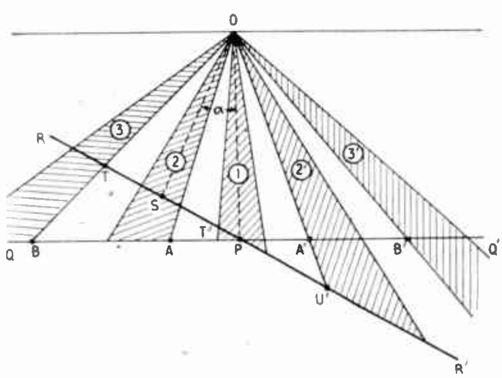


Fig. 5. Interferometer beams or lobes.

If the echo-sounding transducer (which is a fairly large one in a system of high directivity) be replaced by two parallel strip transducers separated by a suitable distance, then the directional pattern obtained in the vertical plane containing the line joining the centres of the two transducers is the well-known interferometer pattern consisting of a number of equally spaced lobes all of approximately equal sensitivity (within a reasonable range of angle from the vertical). The system may be represented diagrammatically and arbitrarily by the beams 1, 2, 2′, 3, 3′, shown in Fig. 5. If, with such a system transmitting pulses, the bottom of the sea is quite level, as shown by the line QPQ′ in Fig. 5, then the first echo received, i.e. the echo showing the shallowest depth, is that from the point P at the centre of the vertical beam. Somewhat later, indicating a greater range, are received echoes from the points A, A′; and after this echoes are received from points B and B′. Thus, if Fig. 6 may be regarded as a sort of idealized recorder trace, then on this level bottom echoes will be received as shown on the left-hand side, where the traces have been reduced to lines. Obviously in practice they will be of some width and all except the first will have some indefiniteness.

Assume that the interferometric plane (i.e. the plane of Fig. 5) is at right angles to the ship's fore-and-aft axis. If now the ship moves forward and eventually goes over a part of the bottom with a slope as indicated by the line RPR′, then the first echo received will in the new circumstances be from the point S along the direction OS. The later echoes from the greater depth are returned from the points T and T′, and then from the points U and U′ and so on; thus the recorder trace, as idealized, will appear as at the right-hand side of the diagram in Fig. 6. If the bottom changes gradually from the level to the sloping position, then the recorder traces may be expected to vary somewhat as indicated by the thinner lines in Fig. 6. If the slope of the sea-bottom lies along the ship's axis rather than across it, then obviously the interferometric plane needs to be turned through 90 deg.

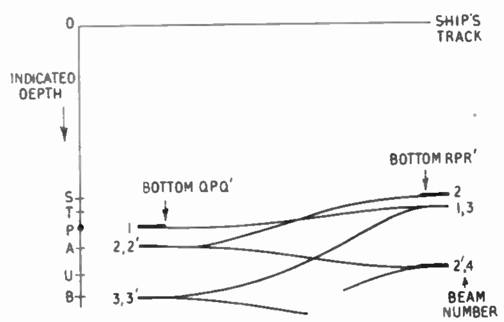


Fig. 6. Idealized recorder traces for interferometric echo-sounder.

It is clear from the above discussion that an interferometric system of this kind gives essentially all the information required. From the record, whatever the depth, provided the echo can be detected from nearly normal incidence on the bottom, then the true depth can be calculated if the bottom slope is known, i.e. the method has the same advantage as that which can be claimed for a wide-beam echo-sounder. On the other hand, if the depth is small enough for effective echoes to be detected even at slanting angles of incidence, then the analysis of the set of traces as shown in Fig. 6 can enable the true depth and the bottom slope itself (which need not be assumed uniform) to be determined when neither of these factors is known. This would appear to be a very considerable advantage for the interferometer.

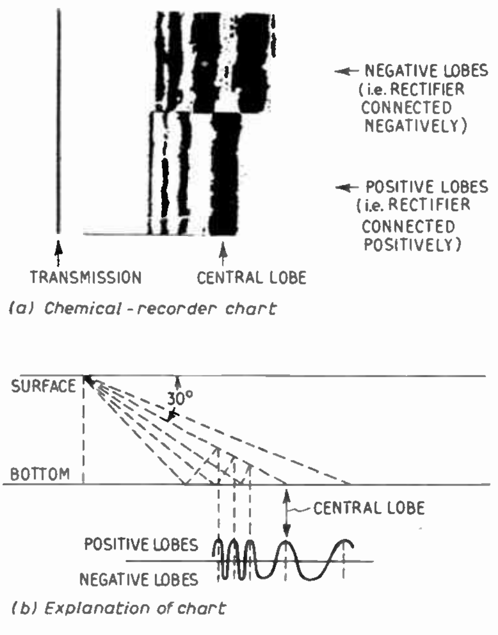


Fig. 7. Test of interferometer in Falmouth Bay using multiplicative reception with rectifier.

(Courtesy *International Hydrographic Review*.)

One point of great technical interest is that the interferometer pattern can be formed (on reception only) by multiplying the outputs from the two sections instead of the more usual adding. This process gives half the lobe-width, and if alternate lobes are removed with a rectifier (the output being d.c. in the multiplicative case) then much more distinct lobes are obtained than in the additive case.

Equipment has been built and trials of the system were arranged to be held in the Atlantic on R.R.S. *Discovery II* in December 1959. Unfortunately, however, the severe weather, with consequent severe "quenching" of the acoustic beams, prevented these trials from being really conclusive. Nevertheless the superiority of the multiplicative arrangement over the additive arrangement was clearly demonstrated, and the effect of the rectifier in the former system is clearly shown in the recorder chart of Fig. 7; the lobes are very distinct.

6. Bottom-Lock F.M. Echo-Sounder

One of the problems in using acoustic echo-ranging devices for locating fish from a trawler is that it is only the fish within say two fathoms of the sea-bottom which can enter the trawl and therefore it is necessary to know specifically whether there are fish in this narrow layer. It is quite feasible for echo-sounders of the ordinary pulse type to have a "bottom-lock" device[12] that refers the origin of the recorder chart to the sea-bottom instead of to the transducer which, of course, moves up and down as the ship pitches and rolls. In this way fish echoes near the bottom can be readily distinguished, whereas normally they are mixed up with the wavy bottom trace resulting from the ship's vertical movement. Unfortunately, however, a bottom-lock device for a pulse system is rather complicated since bottom information has to be obtained and stored before a succeeding echo can be corrected. A frequency-modulation system can deal with the problem more simply, and a bottom-lock f.m. echo-sounder is now being developed at Birmingham.

In a frequency-modulation echo-ranging system[5], the echo appears as a quasi-continuous tone, the frequency of which indicates the range of the target. Now, in echo-sounding, the echo from the sea-bottom must almost always be the dominant echo; and if we assume for the moment that the beam is very narrow indeed, we have at the output of the receiver a strong tone representing the bottom. If, then, the total output is applied to a rectifier (or other non-linear device), all the weaker echoes from fish will form tones at the difference-frequency between their own signals and the bottom echo. If the original frequencies are filtered out, then the output frequencies remaining will indicate, not the depth of the fish below the ship, *but the height above the sea-bottom.* We thus have an extremely simple bottom-lock echo-sounding device. Moreover, a simple filter can enable only echoes from within a given distance above the bottom to appear in the output.

In the experimental equipment now being made, the output tones have been arranged to fall conveniently in the lower audio range, and the filter restricts the output to those signals arising from the two fathoms immediately above the bottom. Thus with a simple aural presentation, if a tone is heard it means there are fish (or other objects) in this layer, and the pitch of the tone gives an indication of the height within this layer.

In giving the explanation above, we assumed for simplicity that the beam was so narrow that the bottom appeared as a pure tone. In practice the beam cannot be so narrow as this, and the range of the bottom from the transducer will be greater at the edges of the beam than at the centre. This means that the bottom echo covers a range of frequency; and evidently if this range covers a significant part of the frequency difference between a fish and the bottom, it will produce difference frequencies at the rectifier which will mask the fish echoes. It would seem that the beamwidth should not exceed a few degrees, and for practical purposes this means operation at a relatively high frequency; and consequently the maximum range of detection will be reduced. It is doubtful whether this is any disadvantage in fishing work; and, in fact, the Marine Laboratories at Aberdeen have recently found[13] a high-frequency (400 kc/s), narrow-beam, limited-depth pulse echo-sounder a great improvement over ordinary types.

The equipment now being made has the following characteristics :

Mean frequency, 400 kc/s. Swept range, 340-460 kc/s.
Maximum depth of sea-bottom, 60 fathoms.
Bottom two fathoms presented as audio signal in range 1020-1700 c/s.
Beamwidth between 3 db points, approx. 3 deg.

7. Continuous-Wave Echo Systems

The use of a continuous-wave system, i.e. one transmitting a continuous pure tone of fixed frequency, is, at least at first sight, attractive for the detection of moving objects. If an object has a component of movement along the beam, the echo received from it has a shift of frequency due to the Doppler effect. The amount of this is given by f_d in the formula

$$f_d \cong vf/1500$$

where f is the frequency of the transmitted tone, and v is the velocity in knots of the object towards the transducer. Thus if $f = 50$ kc/s, and the object is a fish moving at one knot, then $f_d \cong 33$ c/s. If all other bodies, bubbles, etc. (microscopic or otherwise) in the water were perfectly stationary, then the general reverberation (or back-scattering) would all be at 50 kc/s, and the echo at 50·033 kc/s would be easily detectable even if very weak; it could in principle be filtered out by a very narrow-band filter.

In practice, of course, the other bodies, bubbles, etc., in the water are moving, and usually in varying directions and at varying speeds. The components of the reverberation, therefore, have also a Doppler shift of frequency, so that the reverberation has a frequency spectrum of appreciable width, and it is against this that the echo from the wanted object has to be detected. To determine the possibility of detecting fish, say, by this means it is evidently necessary to be able to determine the spectrum spread of c.w. reverberation. This can—and will eventually—be measured for a wide variety of practical sea conditions, but at present the effort at Birmingham is being devoted to finding a basis of understanding and calculation of the effect. To this end, as simple a model as possible has been set up. A tank of water has gas bubbles of fairly uniform size injected through special microdispersers at the bottom; these rise with a fairly constant velocity (unfortunately complicated by spiralling) and ultrasonic waves at 1 Mc/s are transmitted vertically upwards. Figure 8 shows the arrangement in the tank. The spectrum of the back-scattering is being measured by a spectrum analyser. If agreement between theoretical calculations and measurements can be obtained

11. D. G. Tucker, "Directional echo-sounding : some possible improvements in equipment and technique", *Intern. Hydrog. Review*, 37, 1960. (To be published.)
12. R. E. Craig, "Seeing with sound" (see Fig. 2), *New Scientist*, 23 July, 1959, p. 96.
13. R. E. Craig, "Trial of a High-frequency Echo-sounder". Unpublished memorandum, Marine Laboratories, Aberdeen. December 1958.
14. D. G. Tucker and J. G. Henderson, "Automatic stabilization of underwater acoustic beams without mechanical motion of the transducer", *Intern. Hydrog. Review*, 37, No. 1. p. 111, January 1960.

DISCUSSION

Dr. F. R. Harden Jones: Very little is known about the direction in which fish swim in relation to the water currents. The problem is important. The behaviour of the fish might influence the efficiency of bottom or midwater trawls, and it is generally believed that fish use water currents as a directional aid while on migration, swimming upstream against the current to their spawning ground.

It is very difficult to follow the movements of fish shoals in the sea. Some success has been obtained by picking up a shoal by an echo sounder and steaming backwards and forwards over it, and noting the positions on a Decca Track Plotter when the shoal was lost or found. Midwater shoals of herring have been followed for an hour or two by this method, and the results show that the fish drift more or less passively with the current, which was measured from a second research ship anchored nearby.

Sector scanning asdic provides a new tool with which to tackle this problem. Working from an anchored ship, it has been found possible to follow the movements of shoals through the sector and to compare their course and velocity with that of the water current measured below the ship. This technique has been used successfully from R.R.S. *Discovery II* in the Southern Bight, during November, 1959. The c.r.o. presentation was filmed and the results are being analysed. Numerous targets were seen moving past the ship with the tide and there can be little doubt that these were small fish shoals in midwater. The shoals were about five yards in diameter, and were detected at all ranges up to 380 yards. We cannot identify them for certain, but they were probably herring, or horse mackerel. While the complete material has not yet been examined in detail, a preliminary examination shows quite clearly that the shoals were drifting along more or less in line with the tide and with same speed. These results make it very unlikely that a simple "swimming-against-the-stream" mechanism can account for the migration of fish to the spawning ground, and new fields for hypothesis and experiment are thus opened up.

R. N. B. Gatehouse: A description of a fully transistorized instrument developed for shoal-water sounding, which weighs only 4½ lb., may be of some interest (Fig. A). The display is in the form of a meter with graduations from 3 to 32 and the units are feet or fathoms according to the setting of a switch. By the elimination of rotating machinery and thermionic valves, a low power consumption figure of 0·1 W has been achieved. One of the main problems encountered was to reject spurious signals from the ranging circuits, which would cause fluctuations in the indicated depth. These arrive from two sources :—

(1) Echoes from objects suspended in the sea. (Reverberation).

(2) Noise generated in the sea, mainly by rolling shingle and breaking waves.

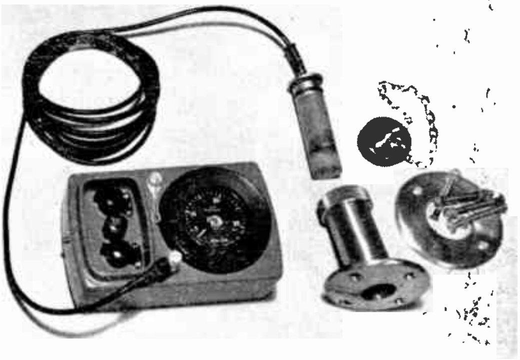


Fig. A.

Except in the case of large fish shoals, the suppression of unwanted echoes was found to be possible by using "swept" gain: a system in which the receiver gain is steadily increased during each pulse cycle, starting from a very low value. An a.g.c. circuit with long "memory" is also used. This is actuated only by the echo in the ranging "gate" and keeps the gain always at the lowest acceptable level, according to reflectivity of the sea bed. The sea noises problem was overcome by the use of a relatively high carrier frequency and by making use of the fact that the information capacity required in a purely bottom-sounding (as distinct from fish-finding) instrument is very low, enabling one to employ receiver bandwidths of the order of only a few hundred cycles per second.

The inclusion of those features results in a complex assembly of circuits, but the instrument is nevertheless compact and reliable owing to the remarkably high efficiency and dependability of transistors.

J. H. Lindars: In the development of echo-sounders for fish detection I have become convinced of the very great importance of a good received signal/noise ratio. The noise in this case is not generated within the sounder, but from the most part comes from the water itself. Some is produced by reflection of the transmitted pulse from air-bubbles, plankton, etc., but with the transmitter powers normally used the greater part is acoustical. The obvious way to improve the ratio is to increase the energy in the transmitted pulse, the receiver bandwidth being chosen to suit the pulse length in use. It is only with the advent of transistors using a relatively long pulse (from 1 to 10 milliseconds) of the maximum power obtainable without cavitation at the transducer face, that reliable fish detection by echo-sounder has become an everyday occurrence in commercial fishing.

In the electronic sector scanning system, it seems to me that since the transmitter must "illuminate" the whole area to be scanned, any given target receives considerably less illumination than it would in a normal rotating-transducer system where transmission and reception are performed on a single transducer or similar transducers. For this reason the received signal/noise ratio would appear to be considerably worse than that of the normal system if a fairly wide sector (say 90 deg. total sweep) were used.

Professor Tucker himself said that with the multiplicative system of reception the signal/noise ratio is worsened. One wonders whether —for fish detection at least—the advantage of a narrower beam is not bought at too dear a price.

Consider a simplified case of rapid scanning in which the transmitter power is evenly distributed over the scanned sector, and the scanning beam width is $1/\alpha$ ($\alpha>1$) of the width of the whole sector. Suppose that the total scan time is equal to the pulse duration, the scanning being unidirectional with very rapid flyback.

In this case the signal from a point target will be received for $1/\alpha$ of its total duration, and may be considered as being a pulse $1/\alpha$ as long as the original transmitted pulse.

If instead of scanning the sector, the beam were allowed to point continuously at this target, the received pulse length would of course be α times as long as it was before. At the same time the amount of noise received on this bearing would be increased α times; hence the signal/noise ratio (assuming that the appropriate bandwidth is used for reception in each case) would remain the same.

Thus it seems reasonable to expect that the signal/noise ratio of such a system is not influenced by the scanning rate, and is the same when scanning as when the beam points to the target continuously.

If however in the stationary case the transmission is allowed to take place on the same transducer as the receiver, the only difference in the received signal will be that it comes from a target illuminated with α times the intensity of the previous case—i.e. the signal/noise ratio is improved by a factor of α. In a normal slow-scanning system this is what happens though of course there is *some* movement of the beam away from the target which reduces the signal strength). Hence one would expect a better signal/noise ratio in the normal system, the difference being greater for a wider scanned sector.

Again, in the interferometric method, noise is received on all the "lobes" whereas the signal is only received on one of them.

Returning to the electronic scanning system, I should be interested to know what Professor Tucker would regard as a reasonable maximum width of sector; his present 12 deg. seems somewhat narrow for general use. Presumably the limit is set by the reduction of maximum sensitivity that must be made in order to maintain even sensitivity in all directions of the scanning beam, the lowest permissible reception sensitivity being fixed by the thermal noise in the receiver?

In f.m. systems, of course, the bugbear is Doppler effect. In the bottom-lock system, would the possible velocity of fish relative to the bottom produce appreciable errors in their recorded distance from the bottom? In normal trawling an error of six feet in this distance at 100 fathoms would be serious.

Commander H. R. Hatfield: When using an electronic form of presentation on a c.r. tube, has Professor Tucker been able to distinguish between echoes coming from fish near the bottom and those coming from, say, isolated small rocks or large boulders, seaweed, coral knobs, etc. I ask this because one of our greatest difficulties at the moment in hydrographic work is to distinguish between these types of echoes using either wet or dry paper on a recorder fitted with a stylus.

Secondly, could Professor Tucker's method of electronic stabilization be applied to an echo sounder working on a frequency of about 9 kc/s? I have in mind the application of a commercial echo sounder which we used for deep water sounding up to 3,000 fathoms.

M. J. Tucker: In connection with the problem of stabilizing an echo-sounder transducer on a rolling ship, the National Institute of Oceanography has found that a useful improvement can be obtained by hanging the transducer as a pendulum in fore-and-aft bearings, which allows it to remain more or less upright as the ship rolls, and which takes up little extra space. The most effective answer, though, is to mount the transducer in a streamlined body towed alongside the ship on a short warp. Not only does this result in a considerably reduced tilting of the transducer, but it gets it away from the aeration produced by the ship, which is a much more important cause of lost echoes in rough weather. With such an arrangement, we have obtained excellent results sounding in about 3,000 fathoms in winds up to force 7. This seems likely to be simpler and more satisfactory than electronic stabilization.

F. Ramage (Associate Member): In his broad band echo sounder has Professor Tucker performed the apparently impossible of producing a broad-band resonant transducer for the transmitter and receiver transducers or are these operated under non-resonant conditions?

W. K. Grimley: I would like to know if it is possible to provide "tapering" on the receiving transducer of the electronic sector-scanning asdic in order to reduce the secondary responses in the scanning pattern. Evidently this matter becomes of importance when the system is used with a vertical beam and when small objects at the edge of the sector (e.g. fish) only a short distance above the sea-bottom have to be detected at the same slant range as the bottom itself in the middle of the sector; the large echo from the bottom, although received on a secondary lobe, may be able to swamp the small fish echo on the main lobe.

L. S. Brodie: The identification of the various beams of the interferometric echo-sounder is obviously a matter of some importance but also likely to be of some difficulty in many circumstances. Would it be possible to "calibrate" the pattern by sailing initially in several directions across a known sloping area?

Professor D. G. Tucker (*in reply*): Dr. Jones's comments are not only interesting in themselves, but they also show how fruitful may be the collaboration of such different groups of scientists as biologists and electronics engineers. We look forward to the full report of the results of the trials.

Major Gatehouse has shown what a compact and foolproof equipment can result from a rigorous concentration on the essential information with consequent simplification of the presentation. But this can be done only when the information is available in a reasonably unambiguous form; in more complex cases, such as those I have concerned myself with, the problem of simple and foolproof equipment is much more intractable.

Mr. Lindars is, I think, considering the electronic sector-scanning system chiefly from the point of view of vertical echo-sounding. With horizontal ranging, detection is nearly always reverberation-limited, so that the power transmitted is—within wide limits—not a critical factor. But no doubt he is correct in saying that vertical echo-sounding is usually noise-limited. In any case, however, the scanning system does not give inferior noise performance if the integration of displayed information is taken into account. Mr. Lindars is correct in his analysis of the signal/noise problem except that he has not taken into account the fact that the scanning system receives α times as many pulses in a given time as a single-beam system with the same parameters. Provided this higher information-rate is utilized (as it usually is), the signal/noise performance of the scanning system is the same as that of a normal system. As far as sector width is concerned, this is really a matter of operational factors rather than technical ones.

Multiplicative reception does, it is true, have a worse noise performance than the normal system, but its other advantages may sometimes more than counterbalance this; again, the choice is operational rather than technical.

Regarding f.m. systems, I do not think fish are likely to move fast enough in the direction of the beam to give a significant Doppler effect; it should be possible to choose a wide enough frequency sweep to make the effect negligible.

In reply to Commander Hatfield, I have to confess that the distinguishing of fish echoes from those due to boulders, etc., is not a matter of which I have any great experience. I would have thought it was entirely a matter of getting higher resolution and, perhaps, using a scanning system. Certainly the electronic stabilization is suitable for the application mentioned, but Mr. M. J. Tucker may be right in saying that other solutions of the problem are better if their operational disadvantages are acceptable.

Mr. Ramage need not fear; we have not achieved the impossible! Our wideband system uses the transducers well below their resonant frequencies.

In reply to Mr. Grimley, it is certainly possible to use tapering on the scanning receiver, and it will be desirable to do so in the circumstances he mentions. But we hope that multiplicative reception—which can be applied to the scanning system as shown in ref. 3—will give a much more satisfactory solution to the problem, which I understand to be a most important one.

I think Mr. Brodie is right about the interferometric echo-sounder. He has certainly put his finger on a weakness of the system; but it is clear that one can hardly expect such a simple equipment, used without any refinements, to give as perfect a performance as a scanning system with all its complexity. It is merely my hope that the system will represent a great improvement over the ordinary echo-sounder.

# of current interest . . .

Commonwealth Broadcasting Conference

Representatives of Broadcasting Organizations from 10 Commonwealth Countries met in New Delhi, between 22nd January and 11th February this year, to discuss such subjects as exchange of information, joint production of programmes, training of personnel, television, and engineering problems. This Conference is held every four years and this was the first time that it had been held in Asia. Previous meetings were held in Sydney and London.

The technical aspects of broadcasting are a particularly important feature of these Conferences, and nearly all the delegations of Commonwealth countries represented included senior engineers.

Formation of Electronics Industry Council

The formation of an Electronics Industry Council has recently been announced in London by the Electronic Engineering Association. For some time, the Association has been having discussions with the Radio and Electronic Component Manufacturers' Federation and a number of other bodies and it has been decided that the new Council will be concerned with the following: electronic instruments, sound and television transmitters, radio communication equipment, radar and radio navigational aids, computers, industrial electronic control equipment and industrial television and the electronic components used therein.

The constitution of the E.I.C. will provide for the adherence of associations or federations of manufacturers concerned wholly or partly in the manufacture in the United Kingdom of electronic components, apparatus and equipment. Exceptions concern equipment, etc., used in the broadcast radio and television receiving industry —which is covered by the Radio Industry Council—and public telephone services—dealt with by the Telecommunication Equipment Manufacturers' Association. The Council will deal with matters affecting the whole industry while its constituent bodies remain autonomous in their own fields of activity.

The offices of the Electronics Industry Council are at 11, Green Street, London, W.1.

Data Transmission Over the Telephone System

Electronic computer users, and potential users of data transmission will shortly receive a questionnaire from the British Post Office asking what data transmission facilities may be needed in the future and saying what Post Office services are currently available. The survey will be made of about 350 organizations including banks, insurance companies, finance houses, industrial concerns and Government Departments.

As more and more computer and punched card equipment is brought into use for commercial, industrial and scientific purposes the necessity for new and sometimes more speedy transmission of data arises. This usually means sending information from branches or departments of an organization to a central point for processing computer or punched card equipment and sometimes the return of information to the originating point after processing. The Post Office already has a varying range of apparatus and lines which can be used for this purpose and is anxious to keep abreast of events and to develop new facilities.

S.T.V.'s New Central Technical Area

Improvement on technical standards has been the aim in designing the new Central Technical area which is shortly to come into operation at Scottish Television's headquarters at the Theatre Royal, Glasgow.

All electronic services have been concentrated into one area located conveniently between the major studios which will result in shorter lines of communication and require less traffic. Another new feature is the attempt to concentrate all camera control equipment for all studios in this new area. There will be two new Presentation studios in the new area—the old Master Control has only one.

To overcome the problem of heat rise in the Control Room much of the heat producing equipment is now sited away from the operational areas. The mains distribution has been arranged to provide continuity under most breakdown conditions. The new Central Technical Area is planned to accommodate a ten-year development, including the possibility of colour television and the 625-lines system.

Recommended Method of Expressing Electronic Measuring Instrument Characteristics

4. VALVE VOLTMETERS †

Prepared by the Technical Committee of the Institution and based on a report compiled by C. S. Fowler (Associate Member)

Introduction

This is the fourth set of recommendations in a series‡ which has the objective of influencing uniformity in the presentation of information on the features, characteristics and performance of electronic measuring instruments and thus assisting in their comparative assessment and selection by potential users. The establishment of standards of performance is not an objective of these recommendations.

Valve voltmeters in their most common form are devices used to measure the amplitude of an alternating voltage, usually indicating the r.m.s. value of a pure sine wave. They are characterized by having an extremely high input impedance at the frequency of measurement. Many instruments have additional facilities for the measurement of other quantities such as alternating current, direct voltage, direct current and resistance; the recommendations provide for these.

Table of Contents

† Approved by the Council for publication on 2nd December 1959. (Report No. 18.)

‡ "1. Amplitude-modulated or frequency-modulated signal generators," *J. Brit.I.R.E.*, **18**, pp. 7-16, January 1958; "2. Cathode-ray oscilloscopes," *J. Brit.I.R.E.*, **19**, pp. 29-36, January 1959; "3. Low frequency generators," *J. Brit.I.R.E.*, **20**, pp. 197-200, March 1960.

U.D.C. No. 621.317.725

	FEATURE	METHOD OF EXPRESSION	REMARKS
		Part 1. GENERAL DATA	
1.1	**Power supply requirements**	.. volts d.c./a.c. .. c/s and/or battery .. watts (Voltage change ± .. %)	Maximum voltage variation for which the stated accuracies hold good must be given.
1.2	**Temperature range**	.. °C to .. °C	Maximum ambient temperature range for which the stated accuracies hold good with nominal power supplies.
1.3	**Accessories**		Details of connectors, adaptors and probes included with the instrument should be given. Are these stored internally?
1.4	**Construction and finish**		Where the construction conforms to a particular specification, the latter should be named.
1.5	**Valve and/or transistor complement**	Type numbers	State if special selection is required.
1.6	**Dimensions**	Height .. in. (.. cm) Width .. in. (.. cm) Depth .. in. (.. cm)	Over all projections.
1.7	**Weight**	.. lb (.. kg)	With batteries if appropriate.
		Part 2. INDICATOR	
2.1	**Type of indicator**	Meter, c.r.t., digital or other form	Give details of any factors affecting accuracy of reading, e.g. mirror scale, damping factor, etc.
2.2	**Type of scale**	Linear, logarithmic, square law, etc. Length .. in. (.. cm)	Give type for each range if different.
2.2.1	Alternating volts/current scales	As applicable	
2.2.2	Direct volts/current scales	As applicable	
2.2.3	Resistance scales	As applicable	
2.3	**Overload protection**		
2.3.1	Meter	YES/NO	State type.
2.3.2	Circuit	YES/NO	State type.

FEATURE		METHOD OF EXPRESSION	REMARKS
	Part 3. VOLTAGE AND CURRENT RANGES—A.C.		
3.1	**Ranges**		Give lowest scale reading that is within stated accuracy for each range.
3.1.1	Voltage ranges	.. to .. V(mV)	
3.1.2	Current ranges	.. to .. A(mA)	
3.2	**Parameter indicated**		Peak, r.m.s., mean, etc.
3.2.1	Parameter measured		Instrument rectifier characteristics, e.g. square-law or logarithmic.
3.3	**Accuracy of calibration**	.. % of scale reading	Maximum error for each range to be given, with frequency limits between which they apply.
3.3.1	Signal source	.. % reduction of scale reading for impedances of 0·1Ω, 10Ω, 1kΩ, 100kΩ, 1MΩ	Peak clipping error to be shown as graph.
3.4	**Frequency range**	.. c/s to .. Mc/s	Range between which stated errors apply.
3.5	**Input impedance**	.. Ω	Give graph of changes with frequency for probe in case or panel terminals and for probe on end of lead.
3.5.1	Unbalanced	.. pF .. MΩ	State in-phase rejection ratio.
3.5.2	Balanced	.. pF .. MΩ	
3.5.3	Differential	.. pF .. MΩ	
3.5.4	Input impedance for current ranges	.. μH .. Ω	
3.6	**Drift**		Without resetting of zero control.
3.6.1	Short term	.. % of f.s.d. for range with most drift	Maximum change in indication over any 10-min period within 7 hr of switching on, but after 30 min warming up period. Supply voltage and temperature assumed constant over 10 min period.
3.6.2	Long term	.. % of f.s.d.	Maximum change in indication over a 7 hr period commencing 30 min after switching on. Temperature and supply voltage assumed to be sensibly constant.
3.7	**Zero setting**	Type	State if required for all ranges.

FEATURE		METHOD OF EXPRESSION	REMARKS
3.8	**A.c. amplifier**	YES/NO	
3.8.1	Type	Tunable or wide band, etc.	Give 3 db bandwidth points.
3.8.2	Output	.. V (max) meter in .. V (max) meter out	State if meter is kept in circuit.
3.8.3	Output source impedance	.. Ω	
3.8.4	Noise at input	.. μV r.m.s. open circuited	For basic instrument and for amplifiers and external multipliers and shunts, if appropriate.
3.9	**Voltage limitations**	.. V	Give maximum voltage to earth and maximum voltage that can be applied between terminals. Also maximum peak inverse volts at probe diode for full frequency range.

Part 4. VOLTAGE AND CURRENT RANGES—D.C.

4.1	**Ranges**		
4.1.1	Voltage ranges	.. to .. V (mv)	Give lowest scale reading that is within stated accuracy for each range. State if external multipliers or shunts are required.
4.1.2	Current ranges	.. to .. A (mA)	
4.2	**Type of calibration**	Linear, logarithmic, square law, etc.	
4.3	**Accuracy of calibration**	.. % of scale reading	Maximum error to be given for each scale and points at which it occurs.
4.4	**Input impedance**		
4.4.1	Voltage ranges	.. μF .. MΩ	Give frequencies at which impedance is measured. (Required to assess a.c. loading.)
4.4.2	Current ranges	.. μH .. Ω	
4.5	**Drift**		Without resetting of zero control.
4.5.1	Short term	.. % of f.s.d. for range with most drift	Maximum change in indication over any 10 min period within 7 hr of switching on, but after 30 min warming up period. Supply voltage and temperature assumed constant over 10 min period.
4.5.2	Long term	.. % of f.s.d.	Maximum change in indication over a 7 hr period commencing 30 min after switching on. Temperature and supply voltage assumed to be sensibly constant.

FEATURE		METHOD OF EXPRESSION	REMARKS
4.6	**Zero setting**		State if required for all ranges.
4.7	**Amplifier**	YES/NO	
4.7.1	Type	Direct coupled or chopper	
4.7.2	Output	.. V (max) meter in .. V (max) meter out	
4.7.3	Output source impedance	.. Ω	
4.7.4	Noise at input	.. μV r.m.s. open circuit	
4.7.5	Zero drift	.. μV per hr	
4.8	**A.c. rejection**	.. db for .. c/s	
4.9	**Voltage limitations**	.. V	Give maximum voltage to earth and maximum voltage that can be applied between terminals.

Part 5. RESISTANCE RANGES

5.1	**Ranges**	.. Ω to .. MΩ	Give mid-scale reading also.
5.2	**Test voltage**	.. V	Give maximum voltage with polarity at terminals for each range. Also state method of generation.
5.3	**Accuracy**	.. % of mid-scale	

OTHER PUBLICATIONS IN THIS SERIES

In addition to the three reports already published and referred to on page 313, the Technical Committee has under preparation two further sets of recommendations which will deal, respectively, with A. C. Bridges and Stabilized Power Supplies.

DEVELOPMENTS IN TECHNICAL EDUCATION

Training of Technical Teachers

With the announcement of the Appeal for funds to set up a staff college for technical teachers, and the Minister of Education's decision to establish a Technical Teachers' Training College in the Midlands, the remaining major recommendations from the Willis Jackson Committee's Report have been implemented. In September 1956 the then Minister of Education, Sir David Eccles, set up a special Committee to report on "the supply and training of teachers for technical colleges," and this Committee, which was under the Chairmanship of Sir Willis Jackson, reported in 1957.

The Staff College. The Willis Jackson Committee stated in the report, "We are convinced that residential conferences lasting two or three weeks for senior members of the staff of technical colleges, would be of considerable benefit to technical education." The purposes of the conferences would be (*a*) to identify and study major problems connected with the aims, ideas and growth of technical education, with a view to stimulating new methods and attitudes in the colleges; (*b*) to foster more catholic understanding in industry and elsewhere, of the functions of technical colleges; (*c*) to keep the teachers in touch with new trends in science and technology.

The Committee thought that this could best be carried out in a congenial atmosphere such as in a staff college of the type which has been in use in industry for some years. In February a joint appeal to industry was made by Sir Willis Jackson and Sir Alexander Fleck, who is to be Chairman of the Governors of the College, for £100,000 to establish the new college. The running costs will be borne by the Ministry of Education, who will make an annual grant of up to £10,000, and local education authorities who will make grants and pay the fees of the teachers; the total annual cost will be £30,000.

The College will take not more than thirty teachers on courses of two to four weeks' duration, and these will run consecutively throughout the year. The entrance will be limited to senior teachers, heads of departments, principal lecturers and some senior lecturers.

The Fourth Technical Teacher Training College. The Ministry of Education decision to establish a College in Wolverhampton which will open in 1962, will certainly be welcomed. There are as present three technical teachers training colleges: Garnett College, London, Huddersfield Technical Training College, and Bolton Technical Training College.

The additional College will probably attract many more mature men and women from the Midlands who are at present unwilling to undertake the year's training in London or in the North. It is also, of course, situated in an area where there are many technical colleges.

It is to be hoped that another of the Jackson Committee's recommendations, namely that better rates of grants should be provided for students taking full time courses of training, will also be implemented in order to attract good candidates and to reduce the loss in income to students coming from industry.

New Diploma in Management Studies

The Minister of Education, Sir David Eccles, has announced a major advance in management education with proposals to develop post-graduate courses and research in this subject, leading to a Diploma. These plans are comparable with the striking advances in technological subjects made by the Colleges of Advanced Technology and major technical colleges. In this way management education will be given its rightful place as an advanced study appropriate for graduates and professionally qualified men and women.

The Diploma will be awarded, not before the age of twenty-six, to students who have completed a course of study which may be full-time (up to one year) or part-time (three years), or a mixture of the two. The Minister hopes in particular that full-time residential courses will be developed. Before entering on the course students will normally be required to hold a degree, Diploma in Technology or equivalent professional qualification. But arrangements will also be made to enable older students without these qualifications, but with substantial practical experience, to take a Diploma course.

Radio Engineering Overseas . . .

The following abstracts are taken from European and Commonwealth journals received in the Library of the Institution. Members who wish to borrow any of these journals should apply to the Librarian, stating full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. The Institution regrets that translations cannot be supplied.

MASER OPERATION

A Canadian paper has shown recently that optimization of relaxation times combined with multiple pumping cannot by itself extend the operation of masers past the liquid nitrogen range and still result in performance comparable to that presently attainable at liquid helium temperatures with three-level masers. The only remaining possibility appears to be that of increasing the pump-to-signal ratio. A possible scheme of maser operation with pump frequency less than the signal frequency has been indicated for systems of four or more levels if certain relaxation time ratios are favourable. To achieve this operation, a rather high degree of control over the relaxation times is necessary. In practice the impurity and self-doping schemes have been shown to result in a reduction of relaxation times of particular transistions by factors as large as 10. At present, however, such techniques are limited to a few materials and then only applicable under very special conditions.

"Relaxation time and multiple pumping effects in masers." A. Szabo. *Canadian Journal of Physics*. **37**, pp. 1557-1561, 1959.

COOLING TECHNIQUES FOR SEMI-CONDUCTOR DEVICES

A recent French paper makes a study of the thermal phenomena which play a part in the cooling of semi-conductor elements under steady state conditions—conduction, convection and radiation. It is then shown how different equivalent thermal circuits can be derived. The main part of the paper is confined to a discussion on the basis of calculations of radiation schemes and the determination of the maximum permissive power of various types of commercially available transistors. Finally the particular case of radiations with complex fin arrangements is dealt with and it is shown that with some reservations the formulae applying to radiations may also be used for arrangements with forced cooling.

"The cooling problem of diode or transistor semiconductor elements: simple calculation of the thermal resistance of radiators and the determination of maximum dissipative power." J. P. M. Seurot. *Onde Electrique*. **40**, pp. 164-182. February 1960.

A NEW MICROWAVE TUBE

A low noise amplifier with transversal modulation of an electron beam and having a large bandwidth, has been described in American literature which, like the parametric amplifier, takes its energy supply an r.f. source (pump). In a German paper a field with circular instead of linear polarization is assumed for this device. The beam rotating in a longitudinal magnetic field interacts with propagating external fields; amplification therefore takes place even when the signal frequency ω exceeds the cyclotron frequency ω_c, i.e. at relatively weak magnetic fields. A relation is given between the pump frequency ω_p and the phase velocity of a delayed quadrupole wave. For a suitable delay the pump frequency assumes values that may be below the signal frequency by any desired amount. In this case the phase condition of the degenerated amplifier does not exist. With a suitable delay of the output line the amplifier may operate as a frequency converter.

"Low-noise electron beam amplifier." J. Labus. *Archiv der Elektrischen Ubertragung*. **14**, pp. 49-53, February 1960.

SPECIAL CATHODE-RAY TUBES

A German paper has recently dealt with fundamentals for the generation of image transformations on the screens of cathode-ray tubes and thus with the possibility of realizing special cathode-ray tubes for arbitrary curvilinear orthogonal or skew co-ordinates. In such tubes, as a first step, the electron beam is pre-deflected in the well-known manner, i.e. with two pairs of deflection plates arranged perpendicularly to each other. Thereafter it passes a convergent lens and a special inhomogeneous constant after-deflection field assigned to the desired co-ordinate transformation which, like the pre-deflection field, is perpendicular to the tube axis. General calculation information is given which allows a determination of the constant deflecting field required for a certain image transformation or a finding of the image transformation produced with a given constant deflecting field. The term "image transformation" comprises any conceivable variation, caused by a constant deflecting field, of the screen display of a cathode-ray tube, such as enlargements, reductions, conversions of Cartesian co-ordinates, into skew or curvilinear co-ordinates, conformal mapping, etc. Possible fields of application are television and radar engineering, general measurement techniques, analogue computers, etc.

"Image transformations on screens of cathode-ray tubes by means of a given constant deflection field." G.-G. Gassman. *Archiv der Elektrischen Ubertragung*, **14**, pp. 71-76, February 1960.

CIRCULAR LOOP AERIALS

Investigations by a Swedish engineer have given the following picture of the travelling wave structure of the aerial current and potential in a circular loop aerial. Rectilinearly travelling waves emanate from the feeding gap and are symmetrically reflected at the aerial. The reflection coefficient is small and the main wave is transmitted along the aerial as a circulating wave. The reflected disturbance will be reflected again, etc. Hence corresponding terms tend to zero with increasing number of reflections.

The reasons for the circulating wave having a phase velocity greater than that of light, and its starting value depending on the aerial radius are connected with the physical character of travelling waves. The current-potential system is stationary and a physical interpretation of stationary travelling waves, obtained in the above mathematical manner must be sought in terms of transient waves occurring when a feeding voltage starts working on an aerial system.

"Current and Potential Distribution on a Circular Loop Antenna." P.-O. Brundell. *Transactions of the Royal Institute of Technology, Stockholm*, Number 154, 1960, p. 33. (In English.)

FREQUENCY SYNTHESIS TECHNIQUES

Design problems of frequency synthesizers for duplex radiotelephony equipment with up to 100 channels are discussed in a recent Polish paper. The circuit is described of the frequency synthesizer in a decimal system generating transmitter frequency and both heterodyne frequencies. The first i.f. is higher than the band of frequencies occupied by the radiotelephone system. The number of quartz crystals for generating n tens of pairs of frequencies is $n+2$. The transmitted frequency is modulated by means of a reactance valve. A mathematical expression of frequency synthesis by solving four simultaneous equations, expressing the principle of operation and frequency stability condition is presented. Problems of high attenuation of parasitic frequencies are discussed.

"Optimal design of frequency synthesizers for radiotelephones." S. Schmidt. *Prace Instytutu Tele-I Radiotechnicznego*, **3**, pp. 97-114, 1959.

TELEVISION BANDWIDTH COMPRESSION

The possibilities of bandwidth compression in television transmission are considered in some detail in a thesis presented at the Technological University of Delft. After a general introduction in which an outline is given and the relation between bandwidth and picture-quality in conventional television is described, an analysis is made of the redundancy present in normal television transmission. Three different aspects of redundancy are distinguished; they are referred to as the statistical aspect, the physiological aspect and the psychological aspect.

The statistical aspect is considered in connection with probability distributions of brightness values of picture elements, correlation between adjacent picture elements being especially considered. The analysis is based on a practical principle of bandwidth compression and the results are compared with those obtained by some other authors.

The physiological aspect of redundancy is considered in connection with the properties of the eye. The properties investigated are resolving power, persistence of vision, differential sensitivity and the perception of colour. Experiments on the resolving power were carried out in order to ascertain the extent to which definition in the screen image can be matched to the place-dependent resolving power of the retina. Persistence of vision was investigated in relation to the perception of discontinuities in motion. Differential sensitivity covers all effects related to the ability to perceive differences in brightness. A description is given of special effects in this field, as well as of proposals which have been made for transmission systems in which a decrease of the required channel capacity is achieved because of these effects. With respect to the perception of colour, a survey is given of the investigations which have been carried out in recent years in connection with colour television, and which have led to the transmission principles now in use in colour television.

Only a few remarks are made about the psychological aspect of redundancy, because this subject is too remote from practical television engineering and therefore unlikely to yield useful conclusions.

The third part of the study deals with transmission systems with narrow bandwidth, notably an N.T.S.C. colour two-subcarrier system which has been investigated by the author.

"Some Investigations on Redundancy and possible Bandwidth Compression in Television Transmission." K. Teer. Thesis of the Technological University of Delft, 1959, p. 122. (In English.)