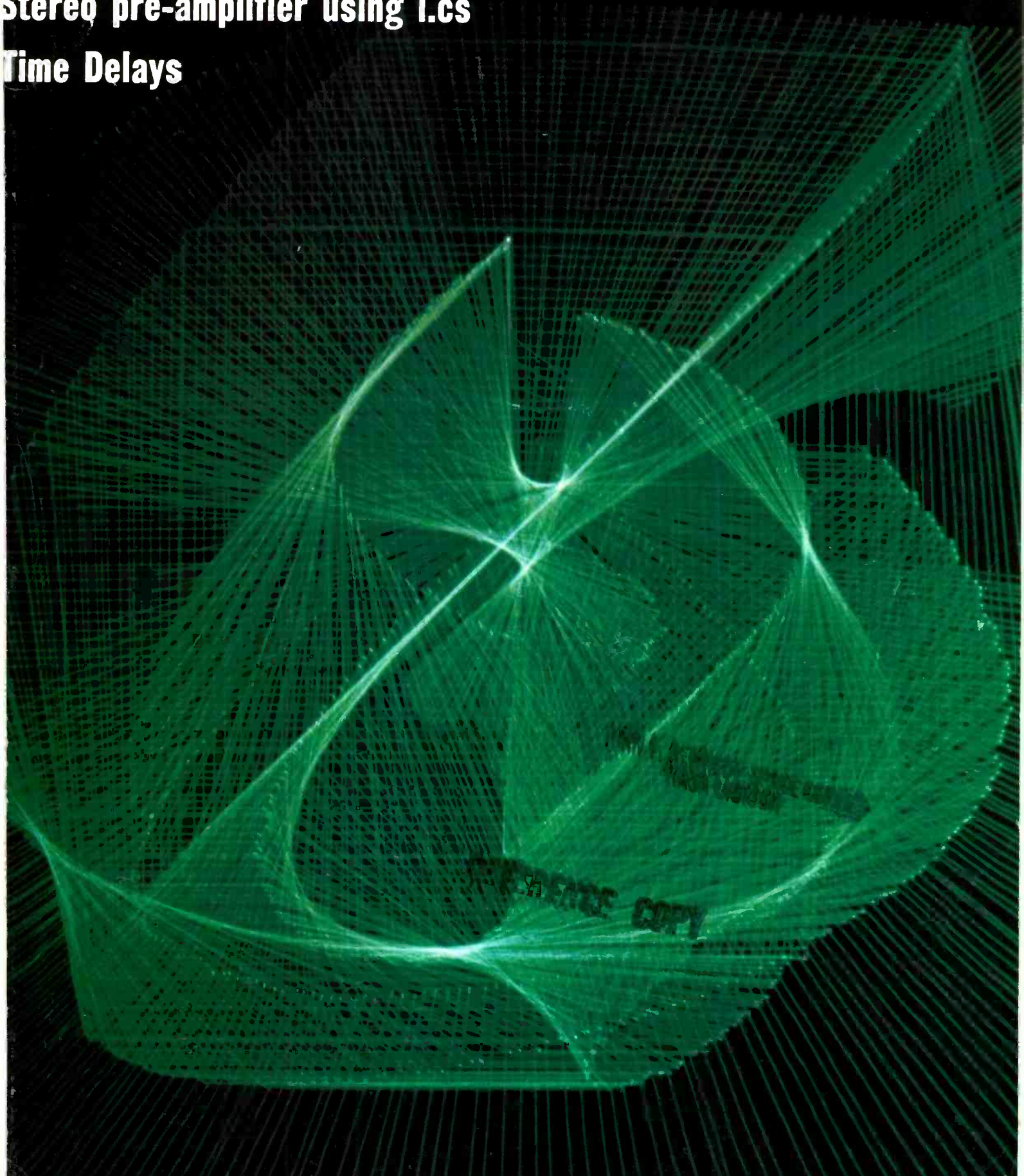


# Wireless World

July 1970 3s 6d

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**Time Delays**



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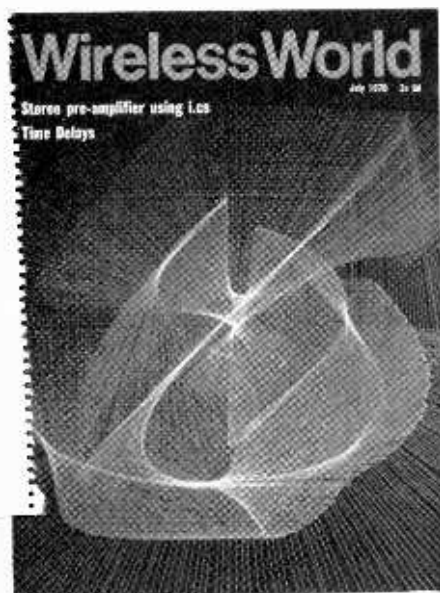
# Wireless World

Electronics, Television, Radio, Audio

Sixtieth year of publication

July 1970

Volume 76 Number 1417



Our cover picture this month was selected on its artistic merits rather than to highlight any particular technical point. The design was produced by a Univac computer and graphic display unit as described on page 315.

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The first of a short series of articles on the design and construction of a television wobulator.

**Colour EVR.** An outline of the system of colour electronic video recording developed by Dr. Goldmark of RCA.

**Morse keyer** using four m.o.s. logic circuits.

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# Wireless World

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We have on several occasions deprecated the proliferation of trade associations within the electronics industry. Our criticism has been mainly of the lack of overall co-ordination rather than of the number of organizations, all of which have performed a useful function, some within a limited and diminishing sphere—in fact in some cases there is no longer a *raison d'être*.

When the Conference of the Electronics Industry (abbreviated C.L.I. to avoid confusion with the Council of Engineering Institutions) was set up, with the top brass of the industry forming the council, it was hoped that here at last was the apex of the broad based triangle. The voice that could speak to governments, other associations and foreign organizations for the whole of the U.K. electronics industry; the industry's co-ordinating authority. As events have shown it was none of these, in fact, except for an annual dinner—at which a few pious platitudes were pronounced—little if anything was heard of its activities. It may, of course, have exerted a powerful influence without ostentation.

It is now announced that the C.L.I. is to be wound up. Will this mean a further fragmentation or will it open the way for another more effective body (the E.E.A.?) to take the helm?

There are certainly significant moves towards the unification of the various trade associations. First, the Electronic Engineering Association is to move later this year into the same building as the British Electrical and Allied Manufacturers' Association where they will share “service departments” and will liaise much more closely than in the past. The interests of the two associations certainly overlap in some areas. A joint “federation council” is to be set up. It is understood that other trade associations have been invited to come under the same roof (if not the same ceiling!) and thereby to save expense. The response however, has not been very heartening from some of them. One suggested that it could best serve the particular sector of the industry, by retaining its independence.

There has, of course, been a marked co-ordination of effort in the components sector of the industry since the formation of the Electronic Components Board. The question of proposed “federal structure” of the whole electronics industry is mentioned in the recent annual report of the Radio & Electronic Component Manufacturers' Federation. In view, however, of “the success of the E.C.B. in establishing an organisational identity for the components sector without prejudice to the internal autonomy of the three constituent associations (R.E.C.M.F., B.V.A. & V.A.S.C.A.) it would seem that the next logical stage in the evolution of an industry federation would be to co-ordinate the policies and activities of the Capital Equipment sector, in which five associations are involved to varying degrees”.

This castigation of the “capital equipment sector” is not without justification. Not only would a federal structure bring added strength, avoiding the “you're treading on my territory” attitude which undoubtedly exists between secretariats, but the manufacturers would be saved the direct costs involved in multi-participation, and the indirect costs of representation on several associations in the capital goods sector.

At the annual meeting of the E.E.A. in March it was stated “We are trying to rationalize our trade associations . . . . . to have a more powerful voice”. It is to be hoped that with the moves now going on we may see the dawn of a unifying electronic industries association in this country such as is operating in the U.S.A. and Japan. With the possibility of a closer link with Europe through the Common Market we will need such an organization to speak authoritatively to its opposite numbers in Germany and France.

# Integrated Circuit Stereo Pre-amplifier

A simple low-noise design especially for use with the author's recently described 10-W class-A amplifier

by L. Nelson-Jones

The power amplifier<sup>1</sup> for which this pre-amplifier was designed has very low levels of noise and distortion, and in order not to impair the overall performance of the system the pre-amplifier had to have a similarly blameless performance.

A note<sup>2</sup> in the May 1969 issue of *Wireless World* particularly interested the author, as it described the use for a stereo pre-amplifier of the R.C.A. integrated circuit CA3048, which consists of four identical low-noise audio amplifiers in a 16-pin dual-in-line package.

The initial study of the integrated circuit centred round the circuit given in the original note in *Wireless World*<sup>2</sup>. This simple circuit (reproduced here as Fig. 1) was soon found to have a number of major shortcomings: the R.I.A.A. equalization network values given proved to be inaccurate at low frequencies; the noise performance was considerably impaired by the 20 dB loss of the passive tone control network; and the high frequency stability of the circuit was poor, as there was a tendency for the amplifier to oscillate at several megahertz producing noise and distortion, even with a carefully planned layout.

In the final circuit these problems were overcome by modifying circuit values, by adding separate tone control circuits of the active-feedback 'Baxandall' type, and by the addition of two capacitors to reduce the gain at radio frequencies thus curing the instability experienced in the original circuit.

## Input stage and equalization

Due mainly to the built-in feedback elements of each section of the CA3048 amplifier circuit, there are limitations on the values which can be used in the equalization network, and also to the total range of gain available for equalization. In practice this means that one has to modify the values which would normally be used with such an amplifier to allow for the parallel internal feedback path. It appears to the author that this had not been done in the original published circuit in the region below about 1 kHz. The author's choice of values corrects the l.f. error at the expense of a slight lift at the h.f. end, due to the previously mentioned limitation of the total range of gain available for equalization. It

was felt, however, that this set of values gave a much flatter overall result and that the h.f. error was in any case too small to be noticeable. In two pre-amplifiers constructed the resultant curves have been within a total spread of 1 dB (between 30 Hz and 20 kHz) of one another.

The stage giving equalization to R.I.A.A. characteristic is used for this purpose only, thus greatly simplifying the switching of the pre-amplifier from one source to another.

## The second stage

The second stage, which has a flat frequency response, uses the remaining two sections of the CA3048 package. The gain of the CA3048 is controlled by the value of impedance seen at the right-hand side of the input long-tailed pair (Fig. 3), which will modify the amount of feedback applied via the internal feedback path. A d.c. blocking capacitor is used to ensure maximum d.c. feedback to maintain the correct operating point. A simple balance control is achieved, as in the original circuit, by the use of a potentiometer at this point so that the relative amounts of feedback to the right and left channels may be varied. The range of this control is deliberately restricted, since the unbalances it has to correct in the equipment should be small, those in normal discs are also small, and serious unbalance in any other stereo source should be put right at source. The range of the

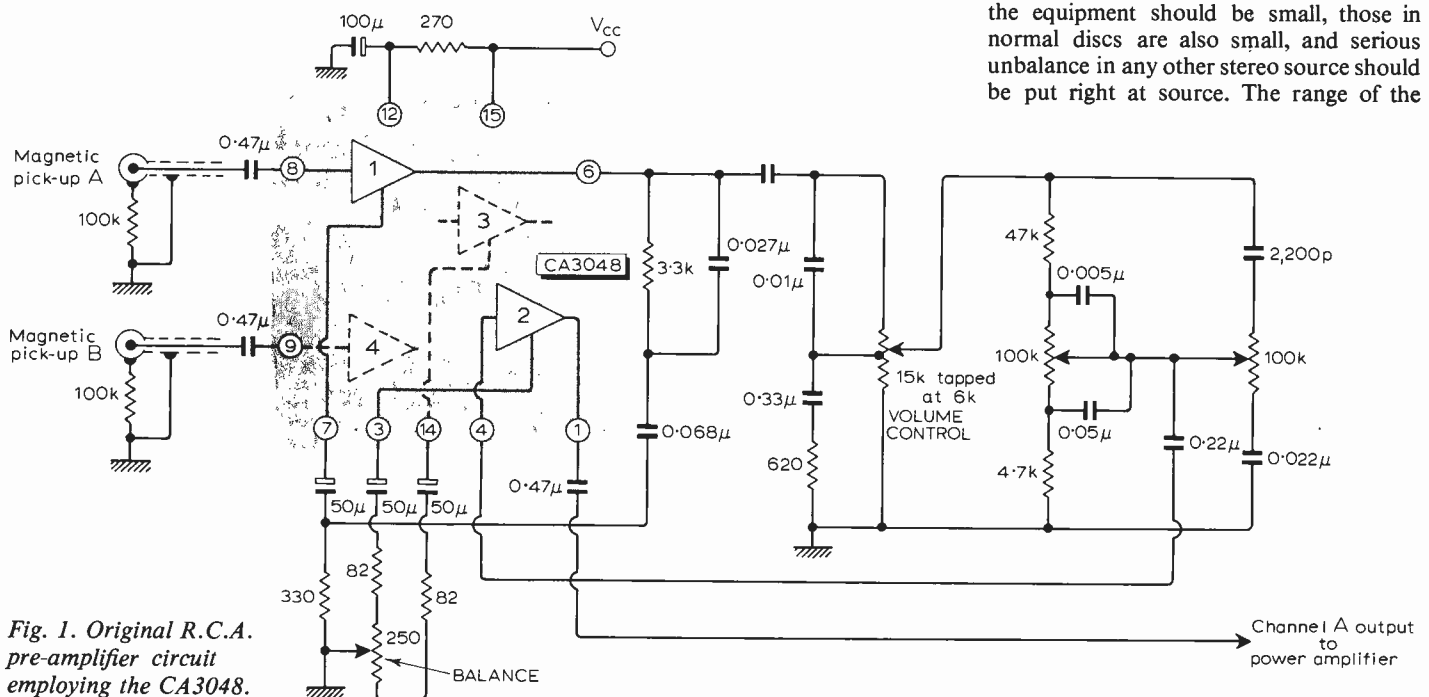


Fig. 1. Original R.C.A. pre-amplifier circuit employing the CA3048.

control as shown is a total of 6 dB on either channel.

This second stage is preceded by the selector switch, and the gain control. The positioning of the gain control at this point is dictated by the need to avoid overloading of the second stage, which would occur if the control were placed after the second stage.

The selector switch connects the auxiliary, and radio inputs direct to the gain control, with a resultant sensitivity of approximately 20 mV for full output (with the 8-Ω version of the power amplifier) of 560 mV r.m.s. Overload occurs at approximately 2 V r.m.s., taking the form of almost symmetrical clipping. Any attenuators used to match this sensitivity to that of

the source should preferably not cause the gain control to be fed by a source of greater than 10 kΩ in order to preserve the very good noise level of the pre-amplifier.

The mono/stereo switch connects the inputs to the gain control in parallel when required.

The instability at first encountered with the CA3048, due to its very high gain-bandwidth product, was at first a problem in the second stage. A complete cure was found in connecting a 330-pF capacitor between slider and lower end of each gain control, together with the additional precaution of a screened lead at this point. The h.f. cut-off produced by this capacitor is well above the audio band, but is effective

in reducing the gain at r.f., and also acts as one arm of a capacitive attenuator to any pick-up on this second stage input.

**Tone controls**

The passive tone control of the original circuit not only degraded the noise figure of the pre-amplifier by 20 dB but also proved to be a difficult one with which to obtain consistent results, there being a considerable tendency for the cut-off frequencies to change with control settings.

The active 'Baxandall' circuit adopted does not suffer from any of these side effects. The nominal 'flat' gain of the circuit is unity since there is no need of further gain, especially as the gain of the second stage has already had to be reduced to account for the removal of the 20-dB gain loss of the passive tone control network.

An additional capacitor of 470 pF is added directly between base and collector of the tone-control stage in order to limit the gain at frequencies above the audio band. The value chosen gives a cut of -0.6 dB at 10 kHz, and -2 dB at 20 kHz, in the flat position of the controls. The purpose of the cut at h.f. is to help to ensure that the power amplifier does not get any appreciable input at frequencies where its power handling is restricted. With an input from discs only, this is not a likely problem, but with tape and radio inputs there are possibilities of higher levels of input above the audio range. Some readers may think the cut is at too low a frequency, and may desire to reduce this capacitor; a value reduction to 220 pF is certainly in order, but it should not be eliminated as it assists in ensuring h.f. stability of the whole pre-amplifier.

Some readers may prefer the use of switched tone controls in which case each of the 2-gang 100-kΩ controls may be

Fig. 2. Circuit of one section of CA3048 and layout of 16-pin package. All four amplifier sections are identical.

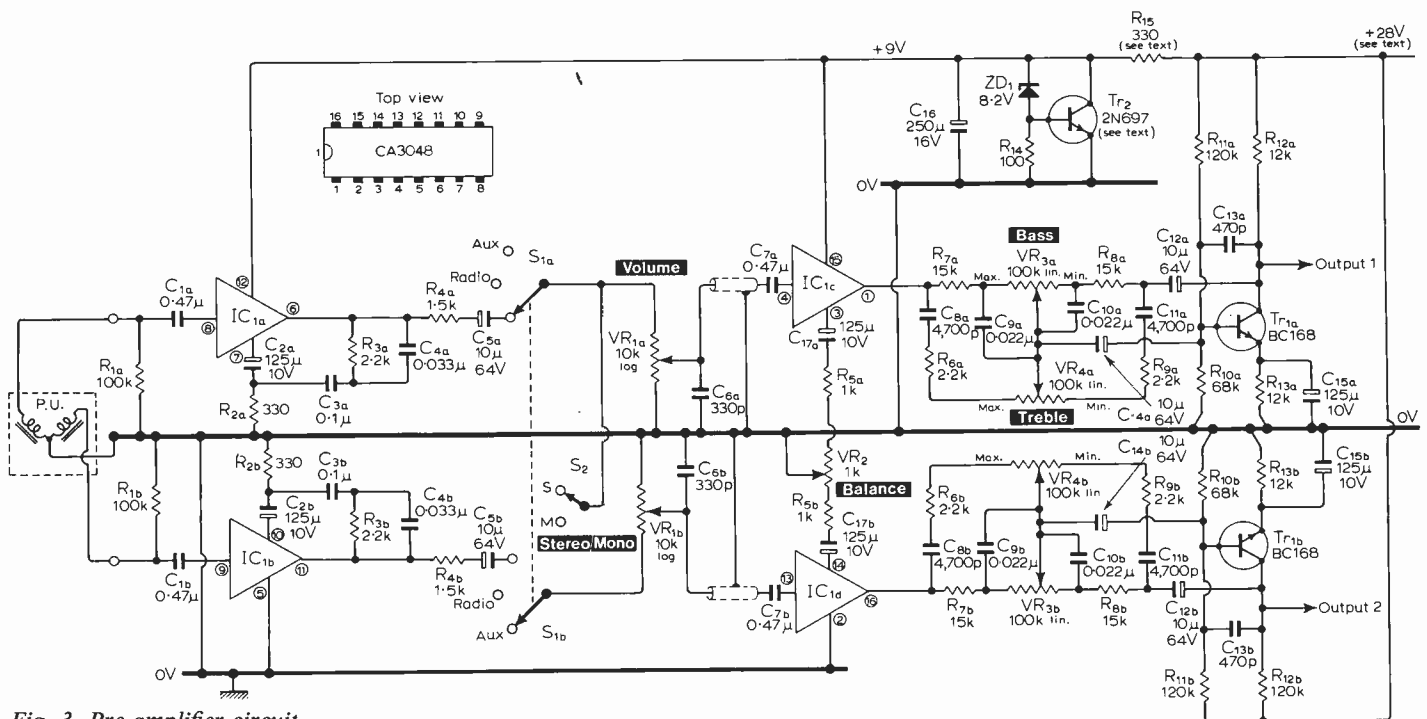
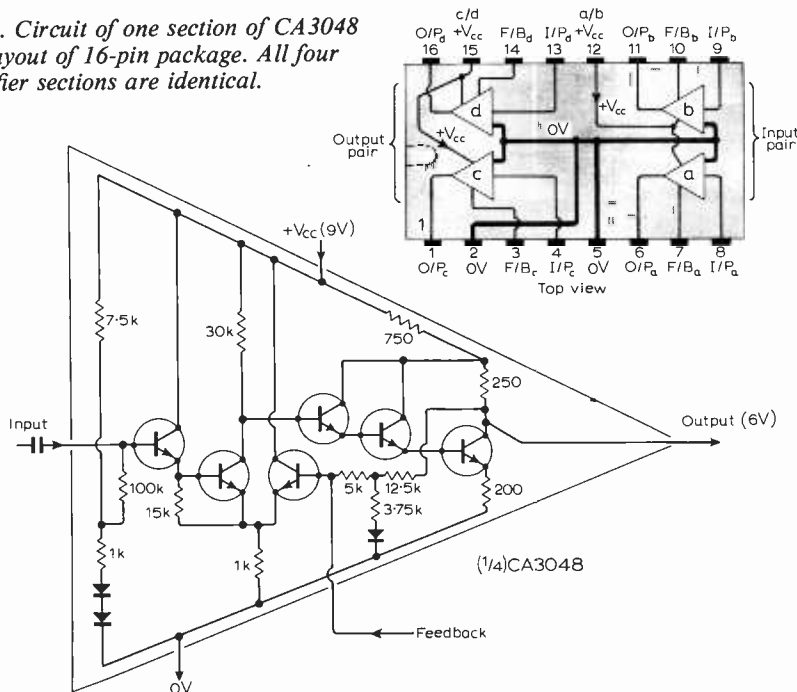


Fig. 3. Pre-amplifier circuit.

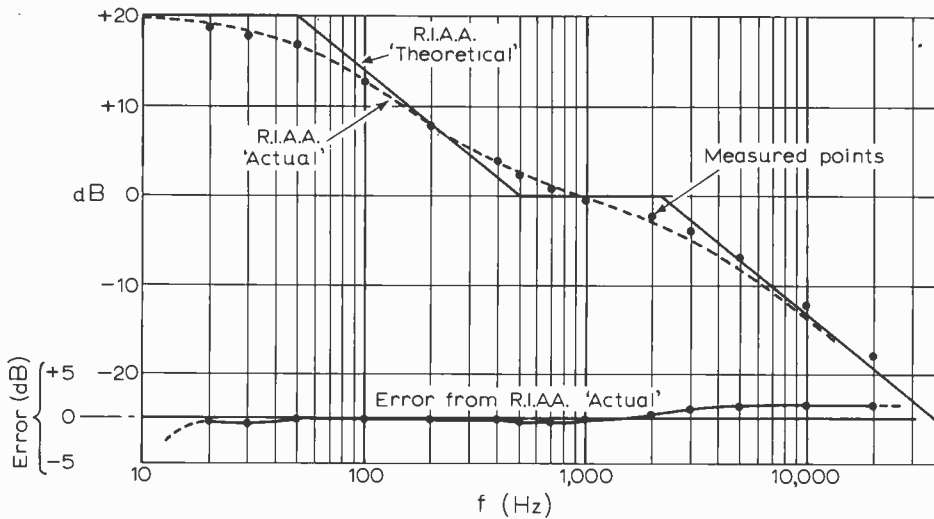


Fig. 4. Input stage R.I.A.A. equalization (tone controls flat).

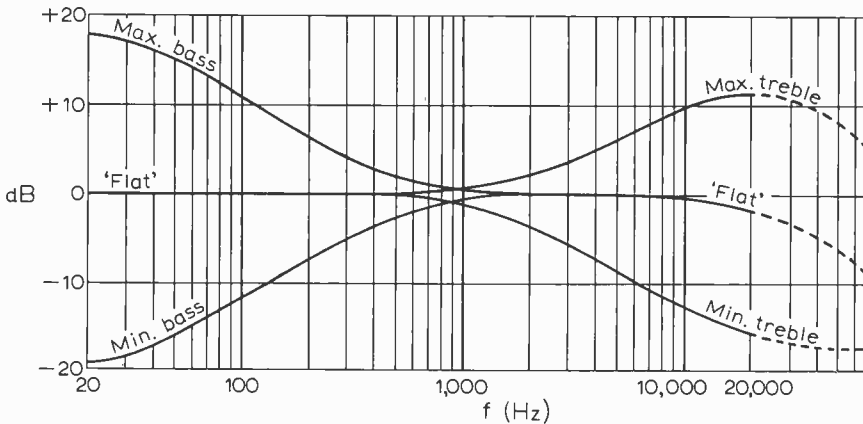


Fig. 5. Tone-control characteristics.

replaced by a 2-pole 7-way switch having six 16-kΩ resistors to each bank, or a 2-pole 9-way switch with eight 12-kΩ resistors.

**Noise performance**

The main source of wideband noise in the pre-amplifier is the second stage. The first stage contributes little as it has such a narrow bandwidth due to the R.I.A.A.

equalization network. The contribution of the input stage is almost entirely 1/f noise which is at a commendably low level and is in any case not particularly audible in practice.

In practice the result is a unit producing no audible hum or noise at any normal setting of the gain control or tone controls. With the gain control set so that peak power reaches 10 watts on a loud recording (5 cm/s at 1 kHz on disc) and with bass and

treble both at maximum (which is the worst case to be met in practice) there is still no audible noise 6 feet from both speakers (which are large units of good sensitivity), and only a very faint hum and hiss can be heard close to the speaker. These excellent results are confirmed by the measurements:  
 (a) Unweighted hum and noise with gain set for 10W into 8Ω (7 mV at 1 kHz from pickup) .... -63.5 dB, rel. 10W  
 (b) Wideband noise alone (less hum and 1/f) ..... approx -80 dB, rel. 10W  
 (c) Unweighted hum and noise at normal listening level (approx. 50 mW average power, 1-2 W peak) ..... approx. -72.4 dB, rel. 10W

This last figure remains fairly constant for all lesser settings of the gain control, and represents the basic noise of the second stage and succeeding stages. The higher level of the first unweighted noise figure is largely due to hum from the windings of the pickup cartridge and 1/f noise from the first stage—both of which are of low audibility.

**9-volt regulator**

The integrated circuit requires a lower voltage supply than that available from the power amplifier. To protect the i.c. in the event of circuit failure, a simple shunt regulator was designed. This type of regulator also ensures freedom from voltage surges at switch-on, and switch-off. An incidental advantage of the use of such a regulator, together with its by-pass capacitor, is a very low cross talk figure for the pre-amplifier between channels. The original circuit<sup>2</sup> used decoupling for the supply to the first stage, but with the low level of ripple, and the low impedance of the supply from this regulator, a better performance is obtained without decoupling to this stage.

The TO-5 transistor of the regulator may be any type having a current gain of over 30 at 50mA, and it should be fitted with a heat-sink as the dissipation is approximately 500 mW.

**Constructional details**

The underside view of the prototype pre-amplifier is shown in Figs. 6 and 7. The CA3048 was mounted on a perforated bakelite 'pin-board' with fine tinned copper links soldered to 16 pins located in two rows on each side of the package. Layout should be kept simple, but is not critical provided reasonable precautions are taken to keep input and output leads separate. The whole assembly should be well screened, and mains leads, mains transformers, and the like kept as far away as possible, to minimize hum pick-up.

The two versions of the pre-amplifier built (one by the author, and one by one of his colleagues) have quite different layouts, yet give almost identical measured results.

**Components**

R<sub>1a,b</sub>, R<sub>14</sub> are ¼W 10% carbon.  
 R<sub>15</sub> is 330Ω 3W wirebound for 28V supply.  
 (180Ω 1W for 19.5V and 470Ω 3W for 36V supply.)

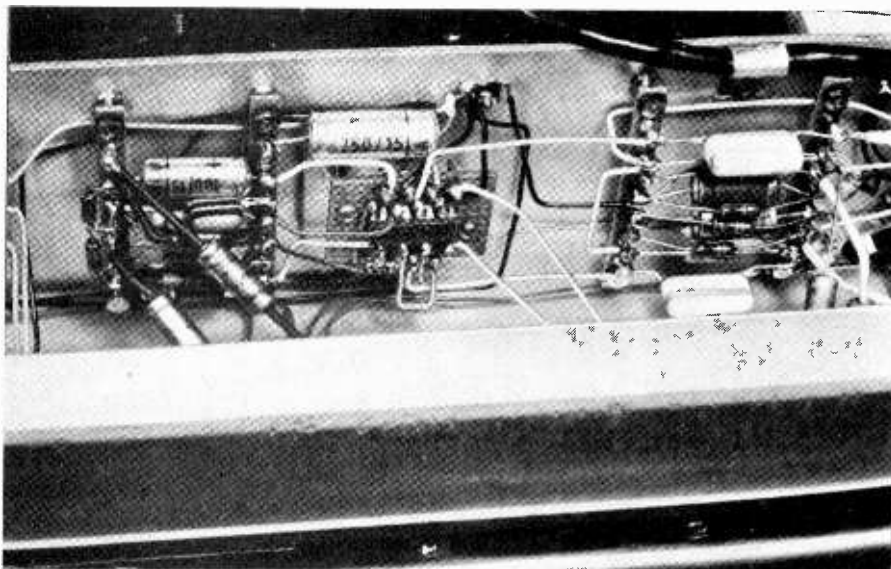


Fig. 6. Close view of the central region of the pre-amp showing the mounting of the i.c. The equalization network is to the left, the tone-control stage to the right, and the two transistors to the extreme right.





Fig. 7. View from the rear towards the front of the prototype pre-amplifier. The supply regulator is at the far end adjacent to the volume control. The tone control circuit is next, adjacent to its controls. The i.c. is at the centre, with the input stage equalization network nearest the camera.

All other resistors are  $\frac{1}{4}$ W 5% 'Histab' carbon or 2%  $\frac{1}{2}$ W metal oxide, the latter being preferable.

$C_{1a,b}, C_{3a,b}, C_{4a,b}, C_{7a,b}, C_{9a,b}, C_{10a,b}$  are all polyester types such as Mullard C280AE or C296AA/A. Capacitor 'a' should be matched to capacitor 'b' within 5% in each case.

(Matching is essential for  $C_3, C_4, C_9$  &  $C_{10}$ , but not absolutely essential for  $C_1$  &  $C_7$ .)

$C_{8a,b}, C_{11a,b}$  &  $C_{13a,b}$  are polystyrene  $2\frac{1}{2}$ % tolerance.

$C_{16}$  is 250  $\mu$ F 16V Mullard C437AR/E/250 or similar.

All the remainder may be Mullard C426 types or similar.

$VR_{1a,b}$  is 10 k + 10 k log stereo potentiometer (2 dB match).

$VR_{3a,b}, VR_{4a,b}$  are 100 k + 100 k in stereo pots (2 dB match). All these twin gang pots. are Radiospares 'Tandem' types.

$VR_2$  is 1 k $\Omega$  in carbon or wirewound.

$S_{1a,b}$  is 3-way 2-pole (prototype uses Radiospares midget wavechange switch 3-way 4-pole).

$S_2$  is miniature rotary type Radiospares 'Changeover SP'.

$I.C._1$  is R.C.A. CA3048 (CA3052 may also be used with a slightly worse noise figure, but is cheaper).

$TR_{1a,b}$  are BC108, BC168, etc. (for the 36-volt version BC107B or 167B would be advisable).

$TR_2$  any good TO-5 n-p-n transistor such as 2N697, 2N1613, 2N3053, etc.

$TR_2$  is fitted with a heat radiator Redpoint 5F.

$ZD_1$  is 8.2V, 250mW, zener diode. Mullard BZY 88-C8V2, Texas 1S2082A, Radiospares MZ-E8.2V etc.

Mainline Electronics Ltd., Thames Avenue, Windsor Berks, are suppliers of

the R.C.A. devices, and Electrovalue and Radiospares the majority of the other components.

### Suitable Cartridges

The pre-amplifier has been designed with the use of a high compliance magnetic cartridge in mind. Most of the magnetic cartridges listed in the recent *Wireless World* summary<sup>3</sup> are suitable. The sensitivity of the pre-amp. is sufficient to allow for the use of the least sensitive, and the overload limit is high enough to allow for the most sensitive in this range.

I am grateful to my colleague Mr. A. Cullen for the use of the results from

his version of this equipment which have been incorporated in this article, and for his co-operation throughout.

I am also grateful to R.C.A. (Gt. Britain) Ltd, for their help with the supply of very full data on the integrated circuit used.

### REFERENCES

1. L. Nelson-Jones, "Ultra-low Distortion Class-A Amplifier", *Wireless World*, March 1970.
2. "Microelectronics at Paris Components Show", *Wireless World*, May 1969.
3. S. Kelly, "Stereo Gramophone Pickups", *Wireless World*, December 1969.

## Computer Graphics

Recently the Univac Division of Sperry Rand Ltd produced several striking multicolour designs using their computers and graphic display consoles. Our front cover this month is an example of one of these. Shapes, which can be distinguished on the picture—squares, triangles, lines and points—were randomly programmed into the computer with no attempt to give them a definite pattern of movement. The tumbling shapes were shown on a graphic display and photographed through several different coloured filters—green and white in the case of our front cover.

A graphic display, one capable of showing engineering drawings, maps etc., is much more complex than the now familiar alphanumeric displays. According to Univac the development of graphic display terminals lags behind that of alphanumeric displays by between three to five years.

Cathode ray tubes are used for both types of display although these will probably be superseded by the laser, or one of the other competing devices, in about five years.

Drawings on graphic displays can be made by causing the c.r.t. electron beam to move between one previously defined point to another such point on the c.r.t. face in a straight line. Curves are simulated using a series of very short straight lines. A graphic display with a c.r.t. with a usable display area of 350 ×

350mm (12 × 12 inches) may have a million precisely defined points on which the beam can be positioned. The million points would be determined by electronics which allow the beam to be positioned at any of 1000 positions in the X direction and at any one of a 1000 positions in the Y direction. The electronics would also allow the beam to move in a straight line between a point on the screen defined by a certain value of X and Y to another point specified by a different value of X and Y.

In normal practice the values of X and Y are fed to the display in binary form from a suitable digital processing equipment.

Often, also under digital control, the brightness of the display can be altered to one of a number of predetermined values. Shapes which are often used can be held in a memory, as subsequent values of X and Y, for use when required.

The computer and the display electronics have to work together to handle the formidable amount of data needed to produce even a simple drawing on the screen and must be flexible enough to allow the drawing to be altered at will.

The recent rapid advances in m.o.s. integrated circuitry is having a marked effect on display design as apart from the control logic and character generation circuits, m.o.s. shift registers are replacing other forms of storage in display equipments.

# Circuit Ideas

## Immersion heater indicator

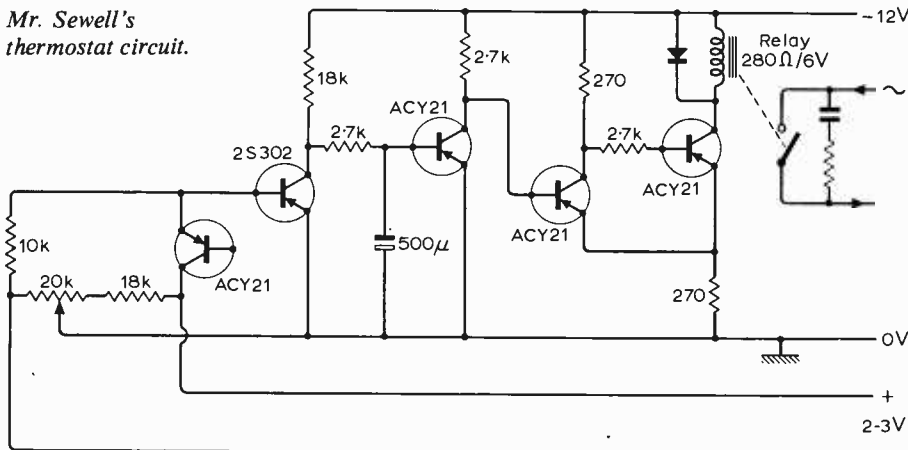
Here is a circuit idea so simple that it does not require a drawing. If an indicator is required to show when a heavy a.c. current is flowing in a cable, for instance, to monitor thermostat and water heater combination, proceed as follows. Strip the secondary of an old bell-type transformer and wind the live wire of the pair to the heater twice round the transformer core (in the space previously occupied by the secondary) and connect a 47-kΩ resistor and wire ended neon lamp in series across the transformer primary. When the thermostat is closed sufficient voltage will be developed across the transformer primary (now acting as the secondary) to light the neon. The idea is useful when the supply cable passes near to the indication point and when long additional cables are to be avoided.

B. S. CRANK,  
Wireless World.

## Sensitive thermostat

The circuit uses a reverse biased germanium transistor sensing element in a bridge. The out-of-balance voltage from the bridge feeds a simple d.c. amplifier driving a relay via a bistable. The bridge components shown are suitable for a temperature range of 12-25°C. The operation is so sensitive that it was found necessary to use the 500 μF capacitor to smooth out short-term fluctuations which otherwise resulted in on-off operation of the bistable. The circuit

Mr. Sewell's thermostat circuit.



has been used for over a year controlling a house central heating pump. The temperature control over the above range has been found to be better than ±0.5°C. For applications with negligible thermal lag, the control is better than ±0.1°C.

A. SEWELL,  
Cheadle, Staffs.

## Schmitt triggers

**Simplified trigger:** The potential divider chain  $R_1$ ,  $R_2$  and  $C$  for biasing  $Tr_2$ , in Fig. 1, can be eliminated by connecting a forward biased diode,  $D_1$  in the emitter of  $Tr_2$  (Fig. 2). The diode should be a silicon type of a current rating to suit the load current of  $Tr_2$  but the voltage rating is not important since it is never reverse biased. Circuit design calculations are simplified and the loop gain is increased for low frequencies.

**Trigger for variable loads:** In Fig. 3 the common emitter resistor is replaced by a zener diode,  $D_1$ , the slope of the zener characteristic providing the feedback for the trigger action. For successful operation the current of  $Tr_1$  must lie below the knee of the zener curve and that of  $Tr_2$ , above. To take an example. Suppose the trigger points are to be between 5 and 6V and the load of  $Tr_2$  consists of 680Ω in parallel with a switchable 6-V 40-mA lamp.  $D_2$  is used to provide the reverse bias for  $Tr_2$ —a conventional bias chain could have been used. On test, using GET111 transistors, an SX56 zener and a surplus silicon

diode for  $D_2$  the trigger points were 5.35V and 5.65V with the lamp and 5.35V and 5.5V without. Fig. 4 makes the operation clear. When  $Tr_1$  is conducting the current is 2mA and the zener is at point P on the curve. When  $Tr_1$  is turned off and  $Tr_2$  conducts, the current without the lamp is about 8.5mA, point Q on the curve, and the voltage at the emitters rises by about 0.2V. Increasing the current to about 50mA, by connecting the lamp, produces only a further increase of 0.2V, point R, as the zener is now on the flat part of the curve.

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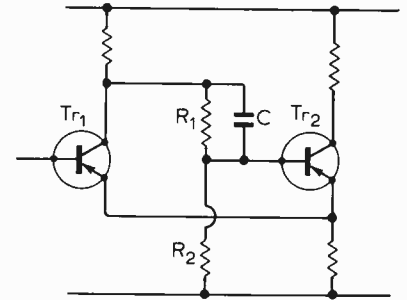


Fig. 1. Conventional trigger circuit.

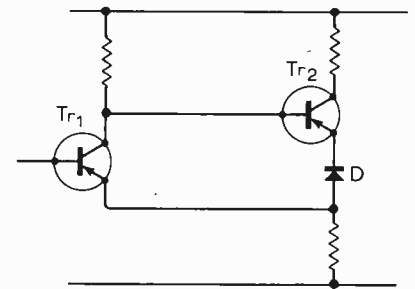


Fig. 2. Using diode to simplify trigger.

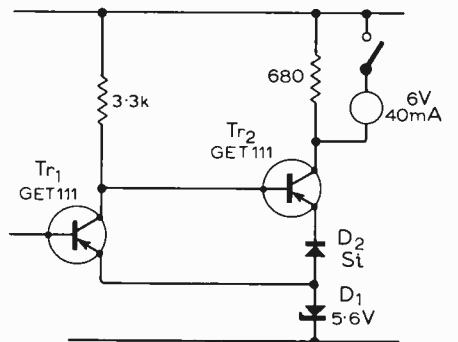


Fig. 3. Zener diode in place of common emitter resistor.

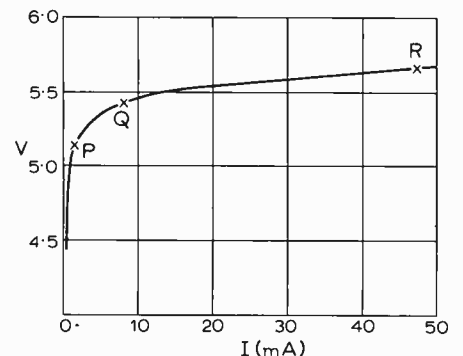


Fig. 4. Characteristic curve of the SX56.

# Time Delays

## A survey of the various methods of obtaining time delays, particularly for use in broadcasting

by H. D. Harwood, B.Sc.

Time delays used in the broadcasting service cover a very wide range from a few nanoseconds in television circuits to several hundred milliseconds in ambiophony† and the applications are correspondingly many and varied. For the purpose of clarity, therefore, delays are described in this article according to the method of obtaining them and the applications of each type are only briefly mentioned. In this connection it will be seen that for some applications more than one type of delay is required.

A description is also given of other types of delay which are not in use in the broadcasting service at the moment but which appear to offer potential advantages in one of the various fields of application.

### All-pass electric circuits

**Coaxial cable:** This is the cheapest and easiest method of obtaining fixed delays of up to about 0.1  $\mu$ s. The velocity of an electromagnetic wave in a coaxial cable is about 0.6 of the velocity of light and a signal made to traverse a length of cable will suffer a delay amounting to 1  $\mu$ s per 180 m of cable. The lines can be accurately terminated and, as the cable can also be made with a high degree of uniformity, reflections can be kept to a low level. Beyond a delay of 0.1  $\mu$ s the volume of cable becomes rather large unless a miniature form is used; but unfortunately, in practice, the miniature type is not so uniform along its length as the standard-size cable and therefore reflections will be more troublesome. The standard cable can be used up to 1 GHz and the cost is very low about £12 per  $\mu$ sec. Applications include equalization of delays for television timing pulses between programme points and central operations room.

**Special delay cables:** The velocity of propagation along a normal coaxial cable is substantially reduced if the inductance of one of the conductors is increased by winding it in the form of a tight helix. As a fur-

ther measure, in one form of cable manufactured by the Hackethal Wire and Cable Co., the centre conductor is wound on a dust core of relatively high permeability<sup>1</sup> thus reducing the velocity still further.

In practice, it is difficult to make the inner conductor as uniform as that of ordinary cable and the variations give rise to reflections which in some cables may be only 20 dB below the main signal.

The impedance of the cable is of necessity high; values for cable made by the British Insulated Callender Cables Company with a polythene core vary from 130 to 1900  $\Omega$ , those for the Hackethal cable vary from 1500 to 3800  $\Omega$ ; the higher values being associated with the greater delays per unit length. For very low velocity cables the delay is not quite constant with frequency but varies by about 10% in the 0 to 4 MHz band and also has a temperature coefficient of 0.08% per °C. The attenuation in the lowest velocity cables is about 3 dB/ $\mu$ s at 6 MHz compared with about 1 dB for the higher velocity cables.

One advantage of this form of delay is the low cost, about 15s per  $\mu$ s; the chief difficulties are that the high impedance makes careful screening imperative to prevent cross talk between the ends; the high level of reflections can also be a nuisance with some cables.

Diameters vary from about 8 to 25.4 mm with delay and manufacturer. Applications include use in pulse generators and for equalizing delays in television programme circuits. A 5- $\mu$ s line has been built<sup>2</sup> by the B.B.C. designs department for the latter purpose.

**LC circuits:** As a further development, a delay line may consist of a single layer coil of insulated wire wound around a core of insulating material covering an earthed conductor; the delay depending on the storage of energy in the dielectric and magnetic fields. This type of line is dispersive in its simple form because the currents in different turns, whilst still magnetically linked, become increasingly out of phase as the frequency rises and changes in delay time of up to 25% may occur within the pass band.

The various means adopted to overcome this difficulty entail breaking the line up into segments. In one method due to Kallman<sup>3</sup> capacitive coupling between groups of turns

is employed; the line being effectively divided up into as many as 48 segments. In this way, the delay was made constant for a 0.9- $\mu$ s line to within 1% over the range 0 to 16 MHz. This rather empirical method was later treated more theoretically by Di Toro<sup>4</sup>, who also gives design data.

Another technique due to Solov'yev<sup>5</sup> uses coaxial shorted turns to sectionalize the magnetic field in the line. In this way, the falling off of inductance with frequency is prevented but, once again, the design details have to be decided by cut and try methods.

The advantage of these forms of line is that they can easily be adjusted on test to give the precise time delay required and are very compact. They suffer, however, from the disadvantage of empirical design and high impedance, 400 to 4000  $\Omega$ , the latter condition necessitating the use of amplifiers and matching networks. Delays of up to 1  $\mu$ s are practicable and are quite cheap to construct. The attenuation is fairly low ( $\approx$  10 dB at 6 MHz) and the reflections are more than 40 dB below the signal.

If the process of sectionalizing is taken further, we arrive at low-pass and all-pass networks. Many designs have been published using low-pass networks but the all-pass types have the following advantages over them.

(i) Their design does not have to take into account the varying frequency characteristic of the network near cut off.

(ii) The characteristic impedance is theoretically constant over an infinitely wide band and, although this cannot be achieved in practice, more sections can be employed before matching difficulties arise.

(iii) The design can be calculated with a high degree of accuracy.

Howorth<sup>6</sup> gives a good example of a 1- $\mu$ s all-pass delay line using ten pairs of networks designed to give a fourth order maximally-flat group delay/frequency characteristic and a constant resistance network to equalize for unavoidable high frequency losses in the coils. Further details are given of staggered pairs of networks up to the tenth order for which a considerable improvement is claimed.

The pass band can be designed to cover any desired range of frequencies, there being no difficulty in achieving bandwidths of 6 MHz. The characteristic impedance is again a matter of design; a figure of 75  $\Omega$

† Ambiphony: A term coined in 1959 by D. Kleis, of Philips, Eindhoven, to describe a system of acoustic feedback designed to modify the acoustics of a room. The sound is picked up by a central microphone, the output of which is delayed by various amounts and then fed back to numerous loudspeakers positioned around the walls and ceiling to modify the reverberation.

would normally be chosen for television purposes.

Delays of up to 10  $\mu$ s can conveniently be made for the video bandwidth and the level of spurious reflections can be kept 40 dB below the signal if individual adjustment of the elements is used. The insertion loss in the line is low, e.g. 6 dB for a 3- $\mu$ s line with a 6-MHz bandwidth.

The cost is higher than that of cable and amounts to about £100 for the example just quoted. The size of such a line would be about 700  $\times$  76  $\times$  76 mm.

Applications include a line of 330  $\mu$ s for the audio band used in a limiter<sup>7</sup> to give the control chain time to operate before the programme reaches the main path.

The delays so far described are fixed in length, although a circular line of the Kallman type could perhaps be produced with a wiper contact. For purposes where a variable delay is essential one known as the Amtec has been produced by Ampex, in which the delay can be rapidly varied by means of an electrical control signal. The delay consists of a series of coils (wound on a common former so that they are mutually coupled) and shunt-connected varactor diodes. The delay is controlled by adjusting the bias on the diodes and a variation of  $\pm 20\%$  is possible at rates of up to 15 kHz. To minimize the changes in delay caused by the signal itself (which appears across each diode), the diodes are connected so as to alternate in polarity along the delay line. The alteration in the characteristic impedance involved in changing the delay limits the usable variation to not more than about  $\pm 5\%$  before excessive echoes and frequency response changes are produced.

Delays of up to about 5  $\mu$ s are possible with this device. The bandwidth is adequate for television signals and when properly matched spurious echoes are 40 dB below the main signal. The impedance is of the order of 300  $\Omega$  and the line will only handle levels of up to 250 mV; amplifiers are therefore necessary before and after the line. The attenuation at 5 MHz is about 6 dB.

The main use is as a servo operated device to reduce the effect of quadrature errors in head alignment in video tape machines; it is also used in line store converters and vertical aperture correctors. The cost is approximately £500 and the size is 700  $\times$  76  $\times$  76 mm.

### Ultrasonic delays

In the delays which have been considered so far the signal has been electrical and the velocity of propagation correspondingly high; this has meant that any delays of more than a few microseconds occupy a considerable path length. In the type of delay to be considered in this section, the signal is converted into a mechanical vibration with a much lower velocity of propagation, and correspondingly higher delays are therefore possible.

For example, the velocity of a shear wave in a quartz block is only 3760 metres per second and this is slower than the velocity of an electrical signal in a coaxial cable by a factor of about  $10^5$ . Furthermore, it is possible to reflect the wave from a number of faces of the block thereby still further re-

ducing the size necessary for a given delay.

A number of substances have been examined for possible use in delay lines; one example is a water line used by the Scophony television system in the early 1930s and again by the Telecommunications Research Establishment in the early days of radar. This was superseded by the use of mercury which gave a much better match to the quartz transducers and had lower attenuation. Solid materials which have been examined for this purpose include metals, plastics, rubber, glasses and gels<sup>8</sup>. Of these solids the lowest attenuation is obtained with glasses and fused quartz and only these are used today.

Similar low velocities of propagation can be obtained from torsional waves in wires and as these can be coiled to form a helix they can be made quite compact for delays up to 20 ms; they are also cheaper than quartz or glass blocks.

**Solid ultrasonic delay lines:** For an ultrasonic delay line fused quartz or glass has the advantage over crystalline materials such as metals in that, being amorphous, the scattering of the waves from crystal boundaries is avoided and hence the attenuation in the medium is less. The attenuation is in fact proportional to the square of the frequency instead of the fourth power as in a crystalline solid. For example, in the region of 10 MHz the mechanical  $Q$  factor of fused quartz is approximately  $10^5$ . In a solid medium, waves can be propagated both in the shear and longitudinal modes. For very short delays, of the order of a few  $\mu$ s, longitudinal propagation is used as it has a higher velocity and thus increases the distance between the transducers for a given delay, so reducing the effects of capacitive coupling between the transducers and the disturbing effects of diffraction near them. For longer delays however the shear mode of propagation is preferable in order to reduce the path length required facilitating a more compact design; the ratio of the two velocities is approximately 1.6 to 1. One of the advantages of the shear mode is that waves are reflected from surfaces with no mode conversion provided the particle velocity is parallel to the surface. Furthermore, the wave may be guided by the top

and bottom surfaces of the block without causing the spurious signals, due to mode conversion, which would occur with longitudinal waves. The major difficulty in using the shear mode of vibration is that of bonding the transducers to the delay medium but this has now been largely overcome by the use of indium cold welds<sup>9</sup>.

For long delays extensive use is made of reflections to increase the path length in a given size block. A good example is shown in Fig. 1 where a 15-sided figure contains 31 legs in the acoustic path between receiving and transmitting transducers. A 1-ms delay line of this type would have a "diameter" of about 14 cm and delays of up to about 4 ms are feasible, with a bandwidth of about 15 MHz. For shorter delays the bandwidth is greater as the attenuation in the medium is less.

The electromechanical coupling of the receiving transducer is so low that very little of the energy in the incident beam is absorbed. The reflected energy returns to the transmitter where it is reflected again to the receiver, forming an echo which has three times the delay of the primary signal. Various means are adopted to reduce the amplitude of this echo. The first measure uses the directivity of the main beam. The transmitter usually consists of a rectangular piece of quartz whose length is long compared with a wavelength and whose directivity is given by:

$$P = \sin\left(\frac{\pi l}{\lambda} \sin \theta\right) \frac{\pi l}{\lambda} \sin \theta$$

where  $l$  is the length of the transducer,  $\lambda$  is the wavelength and  $\theta$  the angle. This represents a main lobe flanked by a null and side lobes, the first of which is about 18 dB below the amplitude of the main beam. With a transmitter about 100 wavelengths long, the directivity is very high, the first null being about 40 minutes of arc and the first side lobe at about 55 minutes of arc away from the axis. In some designs advantage is taken of this null by tilting the axis of the transmitter so that for a "third time around" reflection already mentioned the null is incident on the receiver. The condition for this is given approximately by the relationship  $\theta = 0.4\lambda/l$  (since  $\theta$  is small) and is equal to  $(4 \times 10^8)/f$  minutes of arc for a source of length 1 cm. The reduction in pressure due to the axis of the main beam not being exactly on the receiver is small under these conditions and amounts to only 2 or 3 dB. As a further measure the two transducers are often backed by a wedge of lead; this absorbs a proportion of the energy incident on them, because of the attenuation in the lead.

Also, absorbent material is sometimes fixed to the area of the faces of the polygon which do not carry the main beam. As a result the spurious signals have been reduced in some cases to 60 dB below the level of the wanted signal, although 40 dB is a more usual figure.

The attenuation in the line is largely due to low electromechanical coupling in the transducers for short delays but attenuation in the medium is the limiting factor for long delays. Crystalline quartz is usually used for the transducers but various piezoelec-

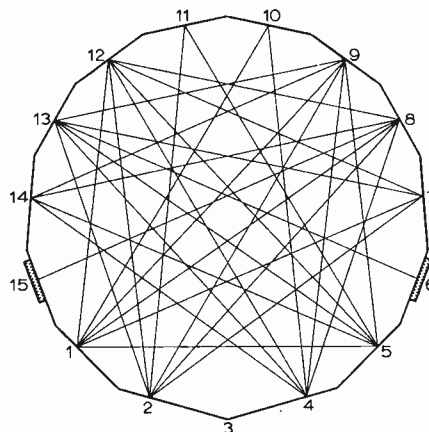


Fig. 1. Quartz block delay line.

tric ceramics<sup>10</sup> have been utilized as they have a coupling coefficient about six times higher than has quartz. They are much more fragile than quartz and there is some difficulty in bonding them to the quartz or glass block.

Fused quartz has a temperature coefficient of about  $-8$  parts in  $10^5/^\circ\text{C}$  and for accurate work must therefore be temperature controlled. For this reason, glasses have been developed with a negligible temperature coefficient but as they have an appreciably higher attenuation they cannot be used for the longer delay lines. Quartz or glass lines have been used for linear field-period delays in television scanning systems as in PAL and SECAM receivers.

For the solid delay lines so far described, the time delay is fixed but there are some applications where it is desirable to be able to vary the time delay fairly slowly. For this purpose an optical scheme of pick off has been suggested by Arenberg<sup>11</sup> and others<sup>12, 10</sup>. When glass is stressed it becomes birefringent; light polarized parallel to and perpendicular to the direction of stress have different velocities. The magnitude of this effect varies with the stress and so can be made to vary the phase between the two mutually perpendicular components into which light can be resolved.

The arrangement used is shown in Fig. 2.

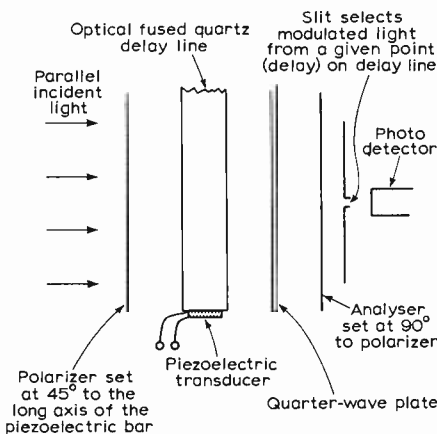


Fig. 2. Quartz variable delay line.

Light from a source is passed through a polarizing medium, a quarter wave plate, the optical delay medium, a defining slit and then through an analyser to a photocell. The analyser is so positioned that in the absence of a signal and the quarter wave plate no light would fall on the photo cell; the presence of a signal would therefore result in a rectified output from the cell. The quarter-wave plate biases the system so that a linear output is obtained from the cell in the presence of a signal. The slit can be moved along the line and continuous variation of the delay can thus be obtained.

One of the difficulties lies in obtaining a good signal to noise ratio, and to this end the stress in the glass is made as high as possible by the use of ceramic piezoelectric transducers which have the highest coupling coefficient.

**Mercury delay lines:** Mercury delay lines are not so cheap or convenient as quartz

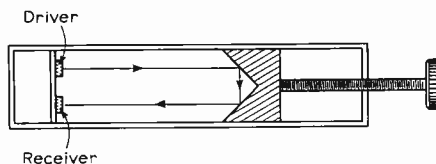


Fig. 3. Construction of a mercury variable delay line.

plates but have the advantage that they are easily adjustable in length, at any rate for delays up to about  $350 \mu\text{s}$ . A typical construction is shown in Fig. 3. As in the case of quartz line a highly directional piezoelectric transmitter generates waves which travel along the mercury and are then reflected back from a corner reflector to the receiving transducer situated by the side of the transmitter.

The attenuation in the mercury is proportional to (frequency)<sup>2</sup> and is given by  $\alpha/f^2 = 5 \times 10^{-15} / \text{m}^{-1} \text{sec}^2$ . This is low for medium frequencies and amounts to about 15 dB at 15 MHz for a 1-ms line. It is obvious, however, that the attenuation increases rapidly as the frequency rises. In the low attenuation region, measures to reduce spurious reflections are essential, and the methods discussed in the previous section are applied. In addition, the transducers are sometimes terminated at the rear by a mercury filled cavity having a shape designed to trap and absorb the incident energy. By these means reflections can be reduced to about 40 dB below the main signal.

As the acoustic impedance of the mercury is a good match to that of the quartz transducers the bandwidth available is wide and the insertion loss due to mismatch is low. The main loss in the system is the poor electromechanical coupling in the transducers themselves, the total loss amounting to some 50 dB for a 1-ms line. The electrical load applied to the receiving transducer also obviously has a marked effect.

The temperature coefficient of delay of mercury in a steel container is  $-0.03\%$  per  $^\circ\text{C}$ . The suggestion<sup>13</sup> has been made that where this is excessive a capillary should be attached to the bath which would thus act as its own thermometer operating a thermostat switch, and control could be exercised to within a few millidegrees.

Static delays of 1 ms and delays adjustable from 30 to  $200 \mu\text{s}$  can be produced. In the latter case the corner reflector is mounted on a lead screw having a pitch such that one complete turn changes the delay by  $10 \mu\text{s}$ . The bandwidth is about 8 MHz. The cost of the adjustable line is about £500 and the size  $400 \times 100 \times 100 \text{ mm}$ . It has been used in a line store converter, a vertical aperture corrector<sup>14</sup> and a field store.

**Ultrasonic wire delay lines:** For these delay lines, waves are propagated along wires using either the longitudinal or shear modes. The expression

$$v = \sqrt{\frac{E}{\rho}}$$

for the velocity of low frequency longitu-

dinal waves ( $E$  is Young's modulus,  $\rho$  is density) is found to be in error at ultrasonic frequencies where the wavelength becomes comparable with the diameter of the wire. Under these conditions Rayleigh gives the velocity as:

$$v_e = [1 - \pi^2 \sigma^2 (a/\lambda)^2] \sqrt{E/\rho}$$

$\sigma$  being Poisson's Ratio and  $a$  the radius of the wire, and this holds if  $a/\lambda < 0.6$ . At the highest frequencies the energy flows almost entirely in the surface layers. Because of the ensuing dispersion, lines using this mode of propagation are restricted to short lengths.

For torsional waves the velocity

$$v_s = \sqrt{\frac{\mu}{\rho}}$$

where  $\mu$  is the modulus of rigidity and is thus free of dispersion provided the wire is straight. If however the wire is curved, as is desirable for long lines, a certain amount of dispersion takes place but this is very low provided the wire is naturally straight, i.e. there is no "set" in the line where it has been taken past the elastic limit.

The diameter of the wire is determined by the fact that only the zero order mode is wanted. Higher orders will exist above a lower cut-off frequency given by  $f_c = (R_n V_s) / 2\pi a$  where  $R_n$  is a constant dependent on the mode, and  $V_s$  is the shear velocity. The value of  $R_n$  for the cut-off frequency ( $f_c$ ) of the first order mode is 5.136. Below their cut-off frequencies these modes are rapidly attenuated and it is safe to use frequencies up to  $0.75 f_c$ .

Another advantage in using the torsional mode rather than the longitudinal mode for long lines, is that the torsional velocity is only 0.6 of the longitudinal velocity with a corresponding gain in delay for a given length. Unlike the quartz and glass considered in the previous section, a wire is composed of a multi-crystalline material. Reflections at the crystal boundaries give rise to additional attenuation, proportional to  $f^4$ , which places an upper limit to the bandwidth.

**Transducers:** Wire lines can be driven by piezoelectric elements but in practice magnetostrictive devices are generally used. For longitudinal modes this takes the form shown in Fig. 4. A short coil surrounds the wire, which is biased magnetically by a permanent magnet as indicated. When a pulse of current is applied to the coil the wire changes dimensions (Joule effect)<sup>15</sup> and this disturbance is propagated in both directions with a velocity  $v_e$ . The wave arriving at the left hand termination block is absorbed

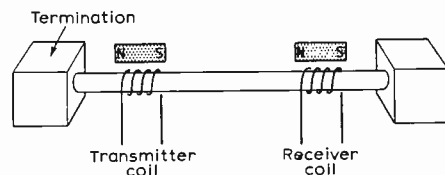


Fig. 4. Driving a longitudinal wire delay line.

and the other travels to the receiver coil, where it induces an electrical signal (Villari effect)<sup>16</sup> and thence to the right hand termination. The length of the coil determines the highest frequency of propagation, the efficiency rising to a maximum at a frequency where  $f = v_0/2l$ .

For torsional modes a converter due to Scarratt and Naylor may be used as shown in Fig. 5. In this case the longitudinal waves are generated in two strips as described above and excite the wire in the torsional mode. To avoid spurious reflections from the driver the termination must be very good. An alternative form due to Wiedemann<sup>17</sup> is shown in Fig. 6. In this case a biasing current flows in the solenoid and the signal current flows down the delay line. In either case the conversion efficiency is low the insertion loss of the two transducers amounting to roughly 40 dB.

The design of a typical long delay line is shown in Fig. 7. Delays of up to 10 ms are available but with these the bandwidth does not usually exceed 1 MHz; spurious echoes

are often as high as -12 dB on these lines. For shorter delays bandwidths up to 5 MHz are feasible. The source impedance should be high and so should the load into which the output coil is connected; matching amplifiers are therefore required. The cost for a line of 3 ms is £70 and the size approximately 178 × 254 × 38 mm.

Because of the limited bandwidth, applications are few. Other ways of producing delays are discussed in the concluding part of this article next month.

## REFERENCES

1. Stein Dimitri, R., "Magnetic Core Delay Cables", *I.R.E. National Convention Record*, 1954, Vol. II, Part 3, pp. 30-34.
2. "A 5  $\mu$ s Delay Panel Type PA7/501", B.B.C. Designs Department *Technical Memorandum* No. 8.125, 1963.
3. Kallmann H. E., "Equalized Delay Lines", *Proc. I.R.E.*, Vol. 34, No. 9, pp. 646-657.
4. Di Toro, M. J., "General Transmission theory of Distributed Helical Delay Lines with Bridging Capacitance", *I.R.E. Convention Record*, Part 5 Circuit Theory, 1953, pp. 64-70.
5. Solov'yev, V. A., "Miniature Delay Line with High Resolution", *Elektrosvyuz*, 1961, No. 2, pp. 11-23.
6. Howorth, D., "Miniature Delay Lines for Television Equipment", B.B.C. *Technical Memorandum* No. T 1083.
7. Shorter, D. E. L., Manson, W. I. and Stebbings, D. W., "The Dynamic Characteristics of Limiters for Sound Programme Circuits", B.B.C. *Research Report* No. EL-5 1967/13.
8. "Preliminary Experiments on the use of Solid Materials as Supersonic Transmission Media for Delay Cells", Telecommunications Research Establishment 2940, 1941.
9. Brocklesby, C. F., Palfreeman, J. S. and Gibson, R. W., "Ultrasonic Delay Lines", Iliffe, London (1963).
10. Gibson, R. W., "Solid Ultrasonic Delay Lines", *Ultrasonics*, April/June 1965.
11. Arenberg, D. L., "Ultrasonic Solid Delay Lines", *J.A.S.A.*, Vol. 20, No. 1, Jan. 1948, pp. 1-26.
12. Brouneus, H. A. and Jenkins, W. H., "Continuously Variable Glass Delay Line", *Electronics*, Jan. 13th 1961, pp. 86-87.
13. Brocklesby, C. F., "Ultrasonic Mercury Delay Lines", *Electronic and Radio Engineer*, Dec. 1958, pp. 446-452.
14. Howorth, D., "Vertical Aperture Correction using Continuously Variable Ultrasonic Delay Lines, B.B.C. *Engineering Monograph* No. 47, May 1963.
15. Joule, J. P., "On the effects of magnetism upon the dimension of iron and steel bars", *Phil. Mag.* 111, 30, 1847.
16. Villari, F., "Change of Magnetization by Tension and Electric Current", *Annalen de physikalische Chemie* 126, 87, 1865.
17. Brocklesby, C. F. Palfreeman, J. S., and Gibson, R. W. G., "Ultrasonic Delay Lines", Iliffe, London (1963), p. 137.

## Mechanical Filters for TV Receivers

Interest in mechanical filters continues to grow and modern microcircuit technology is helping us to obtain smaller and smaller devices working at higher and higher frequencies. Electrical filters depend for their frequency-sensitive effects on the natural behaviour of electrons oscillating between energy stores in the form of capacitors and inductors (or just capacitors in active filters). In mechanical filters the equivalent energy stores are the mass and compliance of lumps of solid material, say metal or crystal, which can be mechanically activated by suitable transducers, e.g. electromagnetic or piezoelectric. For example, some mechanical filters on the market, operating at centre frequencies up to about 20MHz, use thin plates of quartz with pairs of electrodes applied for activation and pick-up.

Recent work has been concerned with mechanical waves travelling on the surface of thin films of material. The latest example, from Zenith in the U.S.A., is an experimental device intended to provide a band-pass frequency response for use in the i.f. sections of television receivers. It uses lead zirconate, a piezoelectric ceramic, and the surface waves are launched and picked up by comb-shaped electrodes; the transmitting "comb" exerts mechanical stress on the material and this causes waves to travel across its surface and create a varying electric field which is detected by the receiving comb. In one example the transmitting transducer is a comb of about 20 teeth in the middle of the area of lead zirconate, while the receiving transducer consists of two combs, one on each side, which can be series or parallel connected. The spacing between the comb teeth is significant in determining the frequency response characteristic of the filter.

A complete i.f. section for a colour television set has been constructed, using four of these devices (known as Surface Wave Integrable Filters) with i.c. amplifiers to compensate for insertion losses, all mounted on a 2in × 1in thick-film circuit on a ceramic substrate. It is said to have given a good picture when substituted for a standard i.f. section in a colour receiver.

Zenith are also working on flat panel television picture displays.

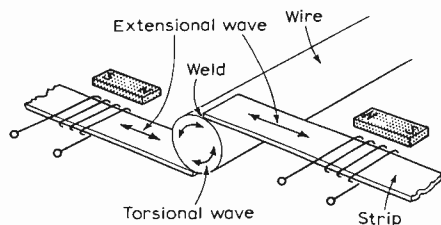


Fig. 5. Driving a torsional wire delay line (due to Scarratt and Naylor).

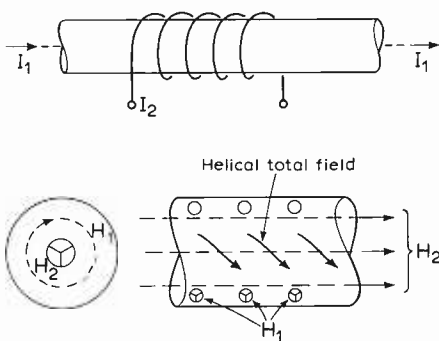


Fig. 6. Wiedemann transducer.

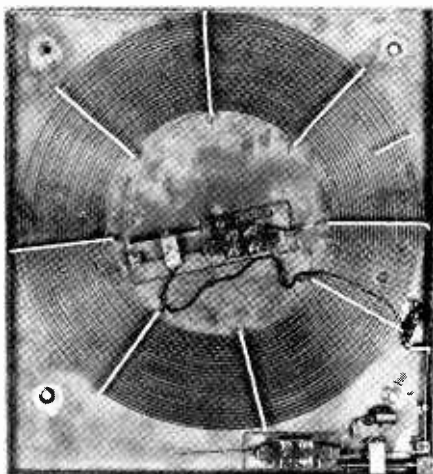


Fig. 7. A typical wire delay line with a long delay time.

# 15-20W Class AB Audio Amplifier

## A design with class-A performance but reduced thermal dissipation

by J. L. Linsley Hood

Many class B designs can be operated in class A at low power levels if the quiescent current is increased. However, this often worsens the distortion characteristics of the output stage, particularly at intermediate (and audibly important) power levels, by displacing the crossover point to a region where the transfer slope is much steeper, and the crossover discontinuity therefore much more prominent. This effect is considerably accentuated by the fact that almost all modern transformerless power amplifier systems use either Darlington pair or augmented (p-n-p/n-p-n) emitter follower output pair configurations, and these have a very high mutual conductance.

The use of a complementary pair of emitter followers, driven from a voltage source having an output impedance which is very much lower than the normal input impedance of the output devices, appeared from this line of thought to offer the best way of minimizing the several problems mentioned above.

In practice, the necessary low impedance base-emitter paths can be arranged quite simply by driving the output transistors from a suitably tapped emitter load resistor in a conventional emitter-follower circuit, provided that the current flow in this load circuit is adequate to deliver the necessary output drive.

Moreover, this type of circuit arrangement will also operate, in class A, as a straightforward cascaded emitter follower, as can be seen from the circuit arrangements shown in Fig. 1. In (a), the transistors  $Tr_1$  and  $Tr_2$  act as a conventional Darlington pair, with a resistive emitter load to which the output load  $Z_L$  is coupled through  $C_1$ . In (b), essentially the same circuit is employed, but using a complementary type of transistor as the second stage emitter follower.

It is then possible to arrange the circuit as shown in (c), so that both of these configurations are employed simultaneously. Resistors of double the ohmic value can then be employed as  $R_1$  and  $R_2$ , with half the emitter current in each transistor, to give an identical matching impedance to the output load. In practice, this circuit arrangement can be simplified into the form shown in Fig. 2, and the resistors  $R_1$  and  $R_2$  deleted since the load current for each transistor can flow through the other. This also improves the efficiency since the transistors have a very high dynamic impedance and form good emitter loads for each other. The two small value resistors  $R_x$  and  $R_y$  are included to assist in stabilizing the output transistor working points.

The actual value of the quiescent current in the output stage can be set by adjustment to  $VR_1$ . To avoid asymmetry, at low audio frequencies, the bypass capacitor should have as high a value as convenient.

This arrangement of the output transistors was of particular interest to the author, since the first three stages of such an amplifier could be substantially the same as those used in the previously described class A design, of which the performance was known. In fact, the system could be constructed on the basis of the class A design, with the quiescent current reduced to a much lower level, and a pair of suitably biased back-to-back emitter followers interposed between the output and the loudspeaker load. However, this would not have made the most of such a system. In particular, it will be noted that if the potential at the emitter (or base) of  $Tr_1$  in Fig. 2 is held constant, the current through the resistor chain  $R_3$ ,  $VR_1$  will be constant for any particular value of

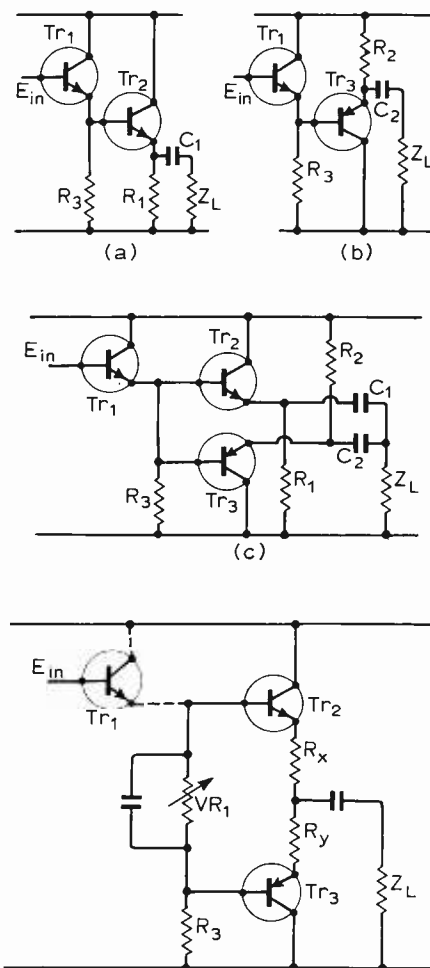


Fig. 1. Emitter follower configurations for class A operation.

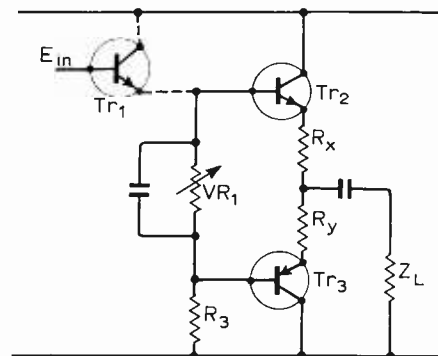


Fig. 2. Simplification of Fig. 1 (c).

$VR_1$  and therefore the turn-on potential applied between the bases of  $Tr_2$  and  $Tr_3$  will also remain constant (or virtually so). This allows the standing current of the output transistors to be defined precisely, since the d.c. output potential can be controlled by the use of unity gain d.c. negative feedback, and this effectively controls the emitter potential of  $Tr_3$ .

Also, since the last voltage amplifier stage is not required to deliver significant power, it can be optimized for voltage gain, with an increase in the available negative feedback. A practical amplifier circuit of this type is shown in Fig. 3.

The first two transistor voltage amplifier stages of this follow conventional design practice, with the collector load resistor of  $Tr_2$  boot-strapped to obtain large voltage swing at the base of  $Tr_3$  with as little second harmonic distortion as practicable. The collector of  $Tr_3$  is also partially boot-strapped in order to reduce the peak voltage swing, and improve the symmetry of the output waveform prior to the application of the loop negative feedback. (Without overall n.f.b. the distortion at full output power is a little

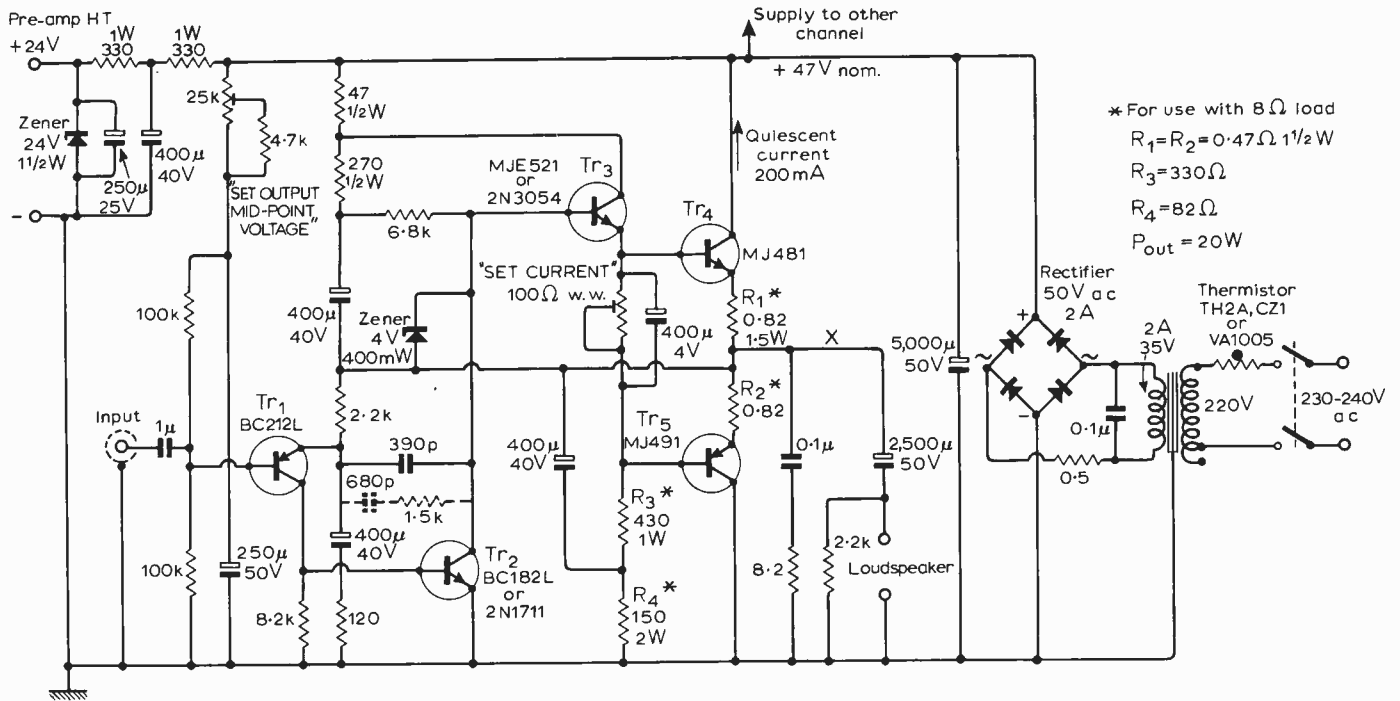


Fig. 3. Power amplifier circuit. The dotted components (680pF, 1.5kΩ) can be added if electrostatic speakers are used.

less than 4%, almost entirely second harmonic. This is similar to the performance of a good triode valve output stage prior to the application of n.f.b.) The lower end of  $R_3$  is also fed with the output signal to improve the output voltage swing obtainable from  $Tr_5$ .

The 390-pF capacitor between the emitter of  $Tr_1$  and the collector of  $Tr_3$ , and the 8.2-Ω resistor in series with the 0.1µF capacitor across the output, provide the necessary phase-angle correction and define the high-frequency gain of the feedback loop. With the values shown there is a 6 dB/octave roll off beyond 100 kHz, and the system is completely stable under all load conditions. However, with the use of a large value capacitive load there will be some overshoot on a rapid transient. The author believes that it is desirable, for tonal purity, for such overshoots to be eliminated, and it is recommended, therefore, that the 390-pF capacitor be shunted with a 680-pF 1.5-kΩ combination where it is intended to drive electrostatic speaker systems. However, on normal loads this merely reduces the h.f. roll-off point, and the power output available in the 30-50 kHz region, and can well be omitted.

The 100-Ω wire-wound potentiometer between the bases of  $Tr_4$  and  $Tr_5$  is used to set the quiescent current level to about 200 mA. The chosen current level determines the power level at which the system changes from class A to class B operation. With the suggested level of 200 mA, this transfer will occur at approximately 300 mW with a 15-Ω speaker (160 mW for 8Ω) although the measured current consumption will not appear to increase until a power output (into 15Ω) of about 1.2 W is reached because the h.t. line bypass capacitor is able to supply the peak current demands.

If the standing current through the output stage is increased, progressively larger output power levels can be obtained within the class A region, up to the level at which the amplifier acts as a pure class A system. The only observed penalty for this exercise is that the power supply demand and the thermal dissipation in the output transistors are both proportionately increased. However, if the output transistors are of dissimilar origin or are otherwise badly paired the operation of the circuit in class A will ensure that the distortion levels and other performance standards are attained in spite of this.

**Performance characteristics**

The specifications given below were obtained using the power supply system shown in Fig. 3. The amplifier was specifically designed to work from a poorly smoothed h.t. line, the values and positions of the h.t. decoupling and 'bootstrap' capacitors being chosen to avoid the intrusion of ripple into the signal circuits. The only significant difference observed in using a good quality stabilized and smoothed power supply is a small improvement in the already extremely good hum and noise levels.

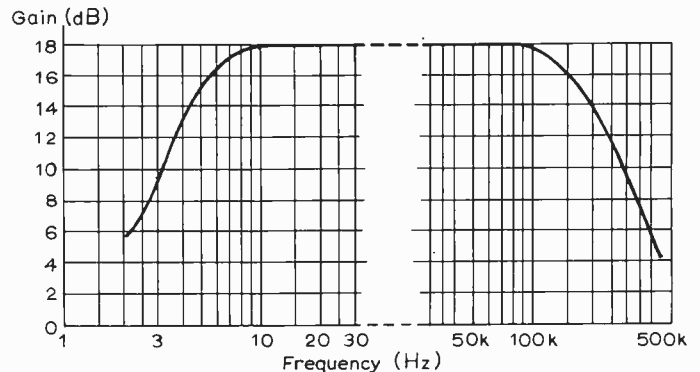


Fig. 4. Gain/frequency characteristics.

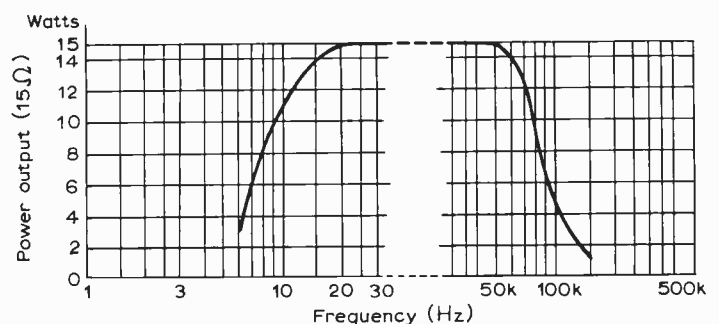


Fig. 5. Power output/frequency characteristics.

- Power output.** 15W into 15Ω, or 18W into 8Ω. (20W with modified output circuit components values).
- Bandwidth.** 10Hz—100kHz ±0.5dB at 2V output. 20Hz—50kHz ±0.5dB at maximum power output.
- Output impedance.** 0.03Ω (at 1kHz).
- Total harmonic distortion.** 0.02% at 15W/15Ω or 18W/8Ω; less than 0.02% at all power levels less than maximum output.
- Intermodulation distortion.** Less than 0.1%. 10W (12.3V r.m.s.) 15Ω, 70Hz. 1V r.m.s. 7kHz (or 10kHz).
- Square-wave transfer distortion.** Less than 0.2W at 10kHz.
- Rise time.** 3µs.
- Input impedance.** 20kΩ (approx.)
- Gain.** 18x.
- Hum level.** (Simple power supply) -70dB w.r.t. 1W



**Noise level.** (Simple power supply) -80dB w.r.t. 1W. (These figures are, respectively, better than -80dB, and -85dB with the regulated power supply.)

**Feedback factor.** 46dB (typical).

**Input voltage for max. output.** 850mV r.m.s.

**Load stability.** Unconditional.

For the perfectionist, a suitable design for a regulated d.c. power supply, with re-entrant short-circuit and overload protection is shown in Fig. 10. This gives approximately 10dB improvement in the hum and (r.m.s.-weighted) very low frequency noise.

The gain/frequency, and power output/frequency graphs are shown in Figs. 4 and 5, and the relationship between output power and distortion, and signal frequency and distortion are shown in Figs. 6 and 7. The square wave performance into a 15-Ω resistive load, with any value of shunt capacitance up to 0.1μF, at 1kHz, 10 kHz, and 50 kHz are shown in Fig. 8. The sine wave output at 1 kHz, and 15W with a 15-Ω resistive load (42.5 V p-p) and the associated harmonic distortion (representing 0.02%) is shown in Fig. 9.

**Listening trials**

As described last month, a number of experiments were done during the development of this circuit to try to relate audible effects to the phenomena observable and measurable in the laboratory, and a transfer distortion analyser (British patent application No. 7925/1970) was made to judge the performance with non-sinusoidal waveforms. (A point was reached in the earlier stages of the design where the author's ear was no longer able to detect the subsequent improvements.)

The transient response of the 10-watt class A design (as originally published<sup>1</sup>, without the modifications<sup>2</sup>, suggested in October 1969 to reduce the h.f. bandwidth) is superior to that of the present circuit in the range 50kHz-2Mhz under load conditions of fairly low capacitive reactance. Under more adverse load conditions the present design will be (technically) better. However, the most careful comparative listening trials, with several of the author's long-suffering friends, have failed to uncover any audible difference between these two designs, both of which will almost certainly surpass in performance the best available valve-operated, transformer-coupled units.

**Constructional points**

The layout used in one of the prototypes of this design is shown in Fig. 11, using a 0.15-in matrix copper strip board. The layout should not be particularly critical provided that normal precautions are observed, such as keeping the output and input circuits reason-

ably well separated, and making sure that the power supply leads, and the loudspeaker return lead, connect to the board at a point close to that to which the collector leads of the output transistors are soldered.

Since the circuit has unity gain at d.c. the occurrence of a switch-on 'plop' in the loudspeaker can be avoided by the use of a suitably long time-constant in the decoupling circuit which provides the base bias for  $Tr_1$ . The voltage at 'X' (Fig. 3) will then follow the base potential of  $Tr_1$  as it slowly rises following switch on. It is undesirable to have the full h.t. voltage applied during this period, and this is avoided by the incorporation of a thermistor (Radiospares TH2A or equivalent) in the mains transformer primary circuit. Since this will cause a drop of some 10-15V, this should be allowed for in the tapping point on the mains transformer. Also, since the thermistor becomes quite hot under operating conditions (this is necessary) it is important to mount it in such a way that this does not damage associated components or wiring.

The dissipation of the output transistors is normally about 8W, and the output pair can both be mounted on a single 3½in x 4in.

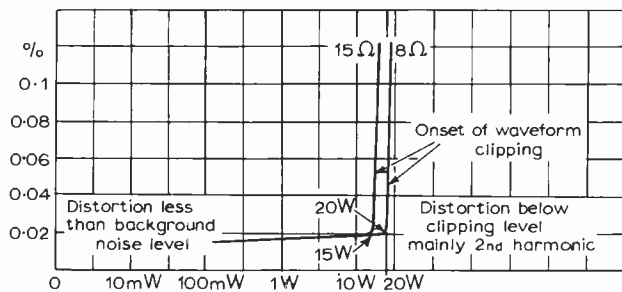


Fig. 6. Power output/distortion characteristics. The 8-Ω load characteristic was measured using the modified output-stage components.

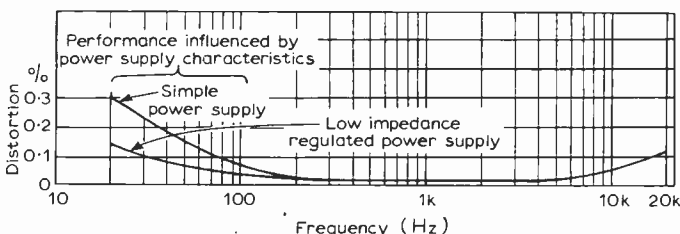


Fig. 7 Influence of signal frequency on distortion (1W into 15Ω)

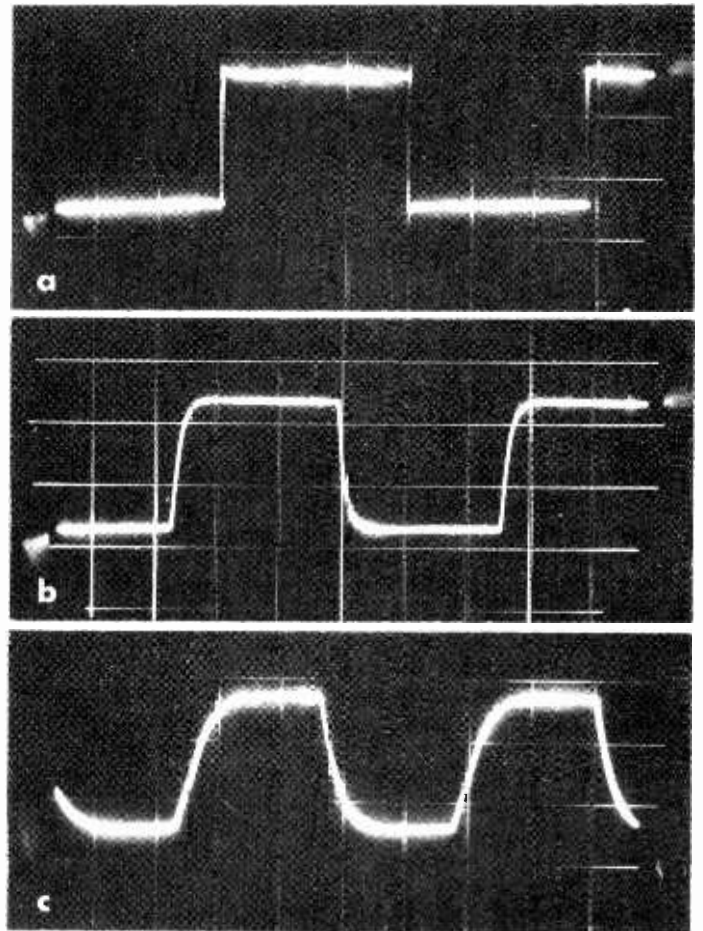


Fig. 8. Square-wave performance into 15Ω in parallel with 0-0.1μF. (Scale 2V/cm) (a) 1kHz, (b) 10kHz, (c) 50kHz.

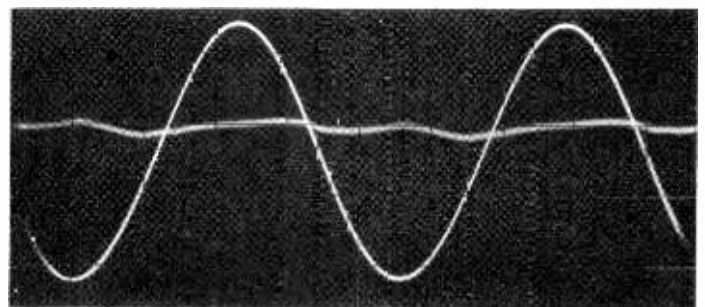


Fig. 9. 14-W 1-kHz sine wave into 15-Ω resistive load. Distortion 0.018% on scale 35mV/cm. Fundamental on scale 10V/cm.

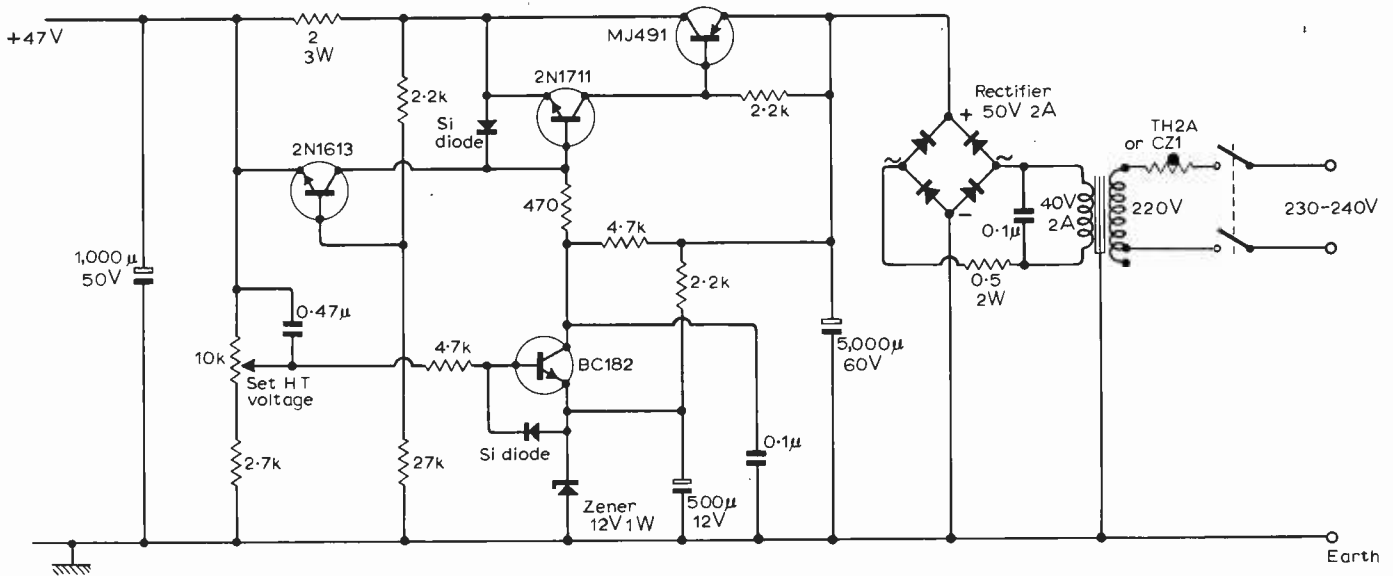


Fig. 10. Stabilized power supply with re-entrant short-circuit protection (12-49V).

black anodized, ribbed heat sink. The heat sink should be earthed—very simply by omitting the mica washer on the MJ491.

The driver-transistor dissipation is of the order of 2W in some circumstances, and this is somewhat in excess of the power which can be handled safely by the normal TO-5 cased device, such as the 2N1613, unless very careful heat sinking arrangements are employed. The use of such devices as the 2N3054 or the Motorola MJE521, mounted on a small piece of black-painted aluminium sheet, say 1 in x 1½ in, gives a very large safety margin in this stage. The performance of the Motorola MJE521 is slightly to be preferred, and was used in all the prototypes. This stage, however, is not a very critical one, and these transistor type variations are unlikely to make a significant difference to the system's overall performance.

The Texas BC212L and 182L are the preferred transistor types for  $Tr_1$  and  $Tr_2$ , although the 2N1613 was also used in some development models as  $Tr_2$  with identical results. The Motorola 2N-3906 and 3904 could also be used in the  $Tr_1$ ,  $Tr_2$  positions with almost equivalent performance, but this has not been tried. The use of ½-W carbon film 5% resistors is suggested except in the points where higher wattages are required.  $R_1$  and  $R_2$  should be of small diameter or low inductance. The various electrolytic capacitors can be of higher value or voltage working without ill effect.

A suitable printed circuit is obtainable from A1 Factors, of Nottingham, who can also supply the other components.

**Appendix 1**

**Calculation of power output levels obtainable with given quiescent current in class A operation.**

The maximum output power which can be obtained from a power output stage such as that in Fig. 3, in class A, is entirely determined by the quiescent current and the load impedance provided that adequate h.t. voltage is available. At frequencies which are low enough for the 'wattless' components of the load current to be ignored, the maximum current excursion which can be caused to flow through the load without taking one or other of the output transistors beyond cut-off is equal to twice the quiescent current ( $I_q$ ) through the output stage. Since this is the 'peak' current through the load, if the waveform is sinusoidal, the r.m.s. equivalent current will be  $2I_q/\sqrt{2}$ , and at low frequencies, the power developed in the load will be  $2I_q^2 \cdot R_L$ .

For example, if the stage is required to operate in class A up to one watt, with a 15-Ω load, the peak current swing through the load must be  $1 = 2I_q^2 \cdot 15$ , or  $I_q = 183\text{mA}$ . Similarly, for an 8-Ω load,  $I_q = 250\text{mA}$ .

With the standing current suggested (200mA), 1.2 watts or 640mW will be given for 15-Ω and 8-Ω loads respectively. This should be adequate for most normal listening. For full class A operation up to 15W, quiescent currents of 710mA and 970mA respectively will be required.

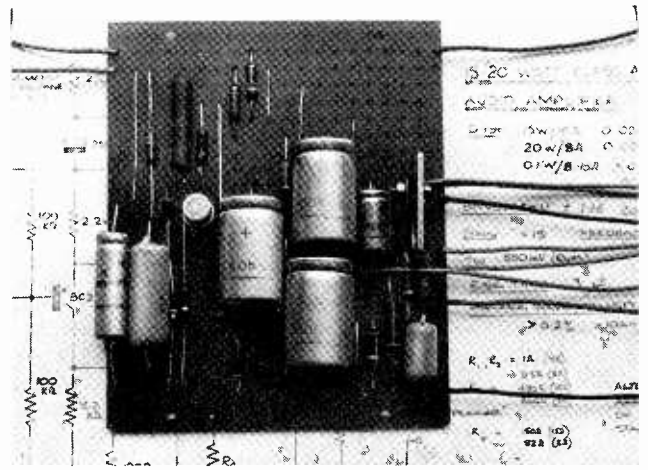


Fig. 11. Layout of components on 0.15-in matrix strip board. The 'set current' and 'set mid-point' potentiometer, and the power transistors, are off the board.

**Appendix 2**

**Output transistor protection**

The use of class B output circuit configuration (and class AB comes within this category at the power levels concerned) in transistor power amplifiers of this general type leads to the possibility that very high instantaneous currents can flow, which will lead, regrettably, to the equally instantaneous destruction of the transistors involved, if the amplifier is operated at maximum drive into an effective short circuit, and this could be a load with a very high capacitive reactance, in some cases.

The classic system for output transistor protection, using two input bypass transistors, is that due to Bailey<sup>3</sup>, and this is also applicable to the output circuit of this design. However, because of the d.c. asymmetry between the potential at the base of  $Tr_3$  and the output point 'X', a much simpler arrangement can be used, consisting solely of a good quality (low leakage) zener diode between these two points, with the positive zener end connected to the base of  $Tr_3$ . Any 4-4.7V zener will do provided that the leakage current at 3V reverse, and 0.4V forward, is less than 10µA. The ITT 400-mW series ZF 4.7 is quite suitable. Again, for 20 W output into 8Ω, the resistors  $R_1$  and  $R_2$  must be reduced to 0.47Ω.

**REFERENCES**

1. J. L. Linsley Hood, "Simple Class-A Amplifier", *Wireless World*, April 1969.
2. "Letters to the Editor", *Wireless World*, October 1969.
3. A. R. Bailey, "Output Transistor Protection in A.F. Amplifiers", *Wireless World*, June 1968.

# Electronic Building Bricks

## 2. Representing information by electrical variables

by James Franklin

Last month we defined electronics broadly as the use of electrons to represent and process information for human purposes. This is a rather grand phrase, and, like all generalizations, needs a down-to-earth example to give it real meaning. Let us, then, look at a simple electronic system.

Fig. 1 shows a system for counting objects moving along a conveyor in a factory. A lamp and lens produce a beam of light which passes across the conveyor belt at such a level that the moving objects interrupt the beam. The light falls on a photo-electric cell, which converts the light energy into electrical energy. The electrical energy from the cell is then conveyed to an electronic counter. This device counts *events*, not, as the name might suggest, numbers of electrons. In this case the events counted are the interruptions of the light beam, as detected by the photo-electric cell.

The graphs in Fig. 2 show in more detail how it works. At (a) is a graph of the light energy reaching the photo-electric cell over a period of time. It will be seen that this energy falls to a very low value, practically zero, when the beam is interrupted by an object (the small residual energy being the result of room light "leaking" into the cell). At (b) is a time graph of the electrical energy generated by the cell as a result of the incident light energy. One can see that it forms a sequence of falls of electrical energy, corresponding to the interruptions of the light beam. These events can be distinguished more clearly if we invert the vertical axis of the graph as at (c).

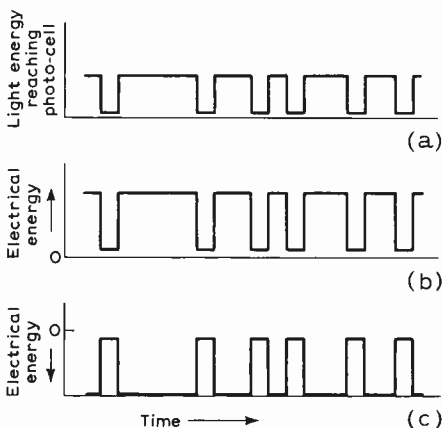


Fig. 2. How the required information in Fig. 1 is represented by an electrical variable: (a) light energy reaching the photo-electric cell; (b) resultant electrical energy; (c) the graph (b) inverted to show falls of energy as pulses.

Thus we end up with a sequence of *pulses* in the flow of electrical energy, representing the interruptions of the light beam and hence the passage of objects through the light beam. The electronic counter counts these pulses—the "events"—and thereby counts the number of objects travelling along the conveyor.

In this simple system the essential information is the number of objects that pass the detection station on the conveyor. Within the electronic system this information is represented by the variation of electrical energy shown in Fig. 2 (c)—a pulse (energy fall) for each object. This graph is one example of an electrical signal. In this form the electrical signal is similar to those produced by earlier methods—smoke, arm positions, flags, flashes of light etc.; it is a sequence of events representing and conveying information.

We have carefully said "representing and conveying" because a signal does both. We may, however, merely wish to represent information, without simultaneously conveying it, so that it may be sent later—this is called *storage*. The two functions are illustrated by analogy in Fig. 3. At (a) the quantity of material held in the container (which can be controlled by the inflow and outflow) may be used to

represent some other variable, say air pressure. This is static information, and the process of holding it, storage. At (b) material is moving along a pipe—this could be the inflow or outflow pipe in (a). Here we could use the rate of flow of the material to represent the variable—and again this could be air pressure. So in both cases we have a mechanical variable made proportional to some other variable, but in one case the information is static (stored) while in the other case it is dynamic (conveyed).

In electronic systems we can use electrons as the "material" in Fig. 3—for example, quantity of electrons for static information, flow rate of electrons for conveying information. There are, in practice, several electrical variables which may be utilized—voltage, power, electric and magnetic fields, to name a few without explaining them here.

Another type of electrical signal is shown in Fig. 4. Although this time graph is a continuous variation of electrical energy in contrast to the pulses in Fig. 2 (c), it can still be regarded as a sequence of events because it consists of successive values of energy (though these successive values are infinitely close together). The electrical energy values here are actually proportional to sound energy values detected by a microphone, and they result from sound waves produced by a violin being bowed on its E string.

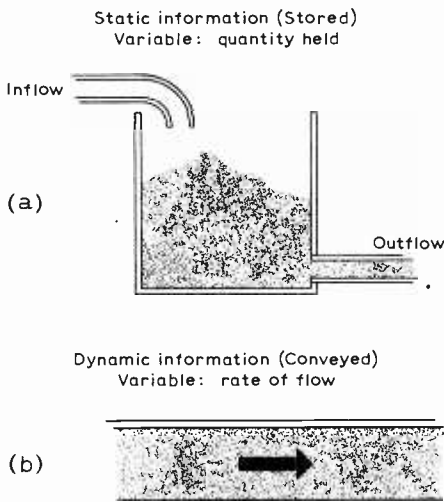


Fig. 3. Analogues illustrating how a material may be used to represent (a) static information and (b) dynamic information.

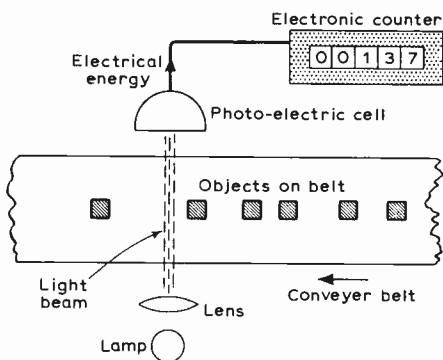


Fig. 1. A simple electronic system for counting objects moving on a conveyor

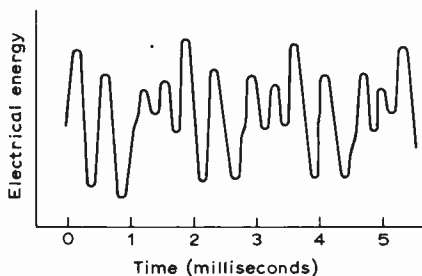


Fig. 4. Graph of electrical energy varying with time—a signal of a different type from that in Fig. 2 (c).

# News of the Month

## Where can you order a $1.35\mu\text{F} \pm 0.5\%$ capacitor?

You can now order a special capacitor of the above value and tolerance in one off quantity and expect a short delivery time. For your 38s 3d, and that is what it will cost you, you will get a high-quality polycarbonate capacitor with either axial or radial leads (your choice) in a rectangular package measuring  $24 \times 14 \times 12\text{mm}$ ; the working voltage will be 63 from  $-55$  to  $+85^\circ\text{C}$ . A temperature swing from  $10^\circ\text{C}$  to  $60^\circ\text{C}$  will change the capacitance by only 0.15%.

In fact the firm which offers this service manufactures 63V polycarbonate capacitors from 470nF to  $22\mu\text{F}$  (any value) with tolerances of  $\pm 5$ , 2, 1 or 0.5%. A  $\pm 5\%$  version of the capacitor mentioned above would cost 11s 4d.

The firm, which is British and is called MFD Capacitors Ltd, is offering a service which is unique, although their main business will be in standard value precision capacitors within the limits mentioned above.

This service is made possible by a new manufacturing process and by a new approach to the problem of determining the capacitance of the final product. Once

the metal-coated polycarbonate films have been wound they are measured and put in bins of a nominal standard value or in bins of a value representing given percentage increments above and below the nominal value. It is normal in film capacitor manufacture for the capacitors in this stage of manufacture to contain short-circuits which are later burnt away by the application of a high-voltage. MFD uses a winding technique that makes this process unnecessary. In fact the polycarbonate film used is so thin (0.002mm) it would be damaged by the process.

Subsequent stages of manufacture—coating the ends of the roll attaching the lead out wires and encapsulation—normally involve the application of heat and alter the value of the winding. The processes used at MFD do not alter the value making it possible to know the final value of the capacitor before manufacture is complete.

Because of this, and because two capacitor 'rolls' can be encapsulated together in the standard cases used, any desired value can be produced by connecting two selected rolls in parallel

within the one encapsulation. In addition MFD will manufacture capacitors in various non-standard packages or with special characteristics.

MFD Capacitors Ltd have announced an agreement with Emihus Microcomponents Ltd under which Emihus will market the capacitors in the U.K.

## Microelectronics industry survey

The Ministry of Technology and the National Research Development Corporation have announced that they are to sponsor a comprehensive study of the microelectronics industry in Britain. It will cover the period 1970 to 1980. The survey will cover forecasts of markets, product costs and technological trends in microcircuits and will include a less detailed survey of the electronics industry as a whole and the ever-expanding list of other industries now making use of microelectronics.

The survey will be conducted by Mackintosh Component Consultants Ltd based in Glenrothes, Scotland, and will take about fourteen months to prepare.

## New transmitter for Criggion

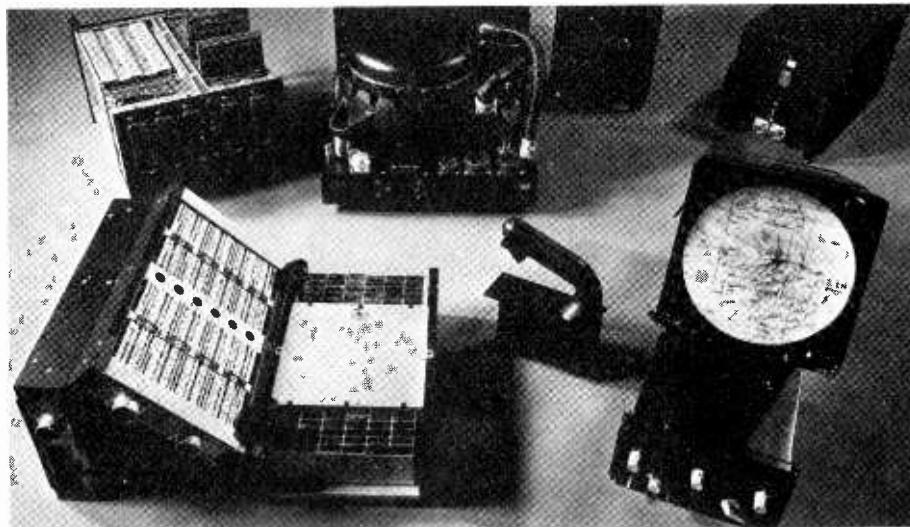
Early in the 1939-45 war it was decided to build a v.l.f. transmitting station that could take over from Rugby (GBR) should this station be put out of action. The shortage of steel for the aerial masts and the need for large amounts of cooling water led to the choice of a site at Criggion near the river Severn. The huge aerial was supported by three 600-ft towers (which had been built for a new radio station in Ceylon) and an anchorage on the top of Breidden Hill which rises steeply above the river Severn.

Hardly had the new transmitting station been completed when, in 1943, the Rugby station was severely damaged by fire. Criggion took over for the nine months it took to rebuild the Rugby station. Following this Criggion, with the call-sign GBZ, operated for 25 years.

In July 1969 a new, larger, aerial was completed on the Criggion site. Three new 700-ft masts were constructed, in addition to the original masts and the hill anchorage. The conductors used for the aerial represented a departure from normal systems for the Post Office in that steel cored, aluminium sheathed cable was employed offering a number of advantages; light weight, strength, high current carrying capacity, freedom from icing and corona, and high capacity to ground. In all fourteen miles of aerial cable, weighing about 40 tons, was used for the aerial.

The new aerial could handle four times the radiated power of the old one and now a new transmitter has been built to provide it. The new transmitter, built by Redifon, was officially inaugurated a few weeks ago. It consists of synthesizer type

*Elliott Flight Automation have received a £5M order for digital inertial navigation and weapon aiming systems to be fitted to Jaguar aircraft for the R.A.F. The basic components of the system, which is built around the Elliott 920M miniature computer, are shown in the photograph. This system is much smaller and lighter than Elliott's first i.n. system which was designed for the Blue Steel stand-off bomb carried by V-bombers.*



frequency generating equipment driving three amplifiers.

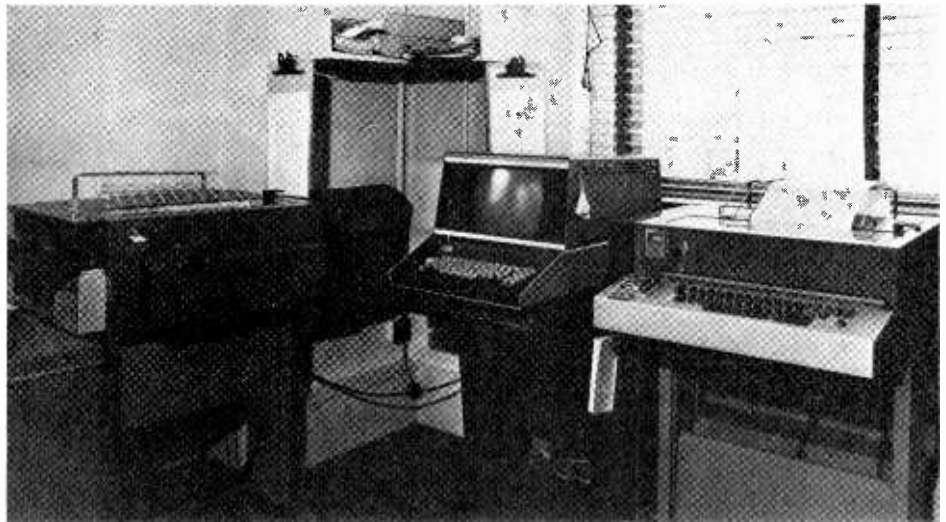
Each of the amplifiers comprises a 5-kW wideband audio frequency amplifier, coupled to a single-stage tuned amplifier having an output of 150kW. Each or all of these three tuned amplifiers can be connected via heavy-duty r.f. switches to the common tuned tank and aerial circuit, and thence to the aerial system. The power fed to the aerial can, therefore, range from 150kW to 450kW, according to the number of amplifiers in use. The tuned output and aerial circuits are of orthodox design employing tuning capacitors of the type first used in the GBR transmitter forty five years ago. The anode tuning inductors are of the variometer type originally developed for a new transmitter built for the Rugby station. The aerial tuning inductor is a modified design of the one previously used at Criggion. The combination of the new aerial and amplifiers has raised the radiated power from approximately 7.5kW to 30kW at 19.6kHz, at which frequency GBZ normally operates.

## Skynet-2

Hawker Siddeley Dynamics Ltd and GEC-AEI (Electronics) Ltd have each been given a contract by the Ministry of Technology to develop, in co-operation with American industry, proposals for higher powered Skynet communications satellites for defence purposes. A decision on which firm is to be the eventual prime contractor for two such satellites will be taken later this year. The craft are to be ready for launching in 1973 to replace the first two Skynet satellites which were built in America. The first of these was successfully launched last November. The replacement satellites will be more powerful and will be able to operate with small transportable ground stations.

## U.K. exhibit at Mesucora

Under the sponsorship of the Electronic Engineering Association and with the support of the Board of Trade, under its joint venture scheme, a number of U.K. companies exhibited at the Mesucora exhibition held at the Palais de la Defense, Paris, from May 27th to June 4th. The companies who took advantage of the joint scheme are: Automatic Systems Laboratories, Ceta Electronics, Electronic Associates, the EMI group of companies (comprising EMI Systems and Weapons Division, S.E. Laboratories, Electron Tube & Microelectronics Division, EMI Tape and Meterflow), Ether, Eurotherm, J. J. Lloyd Instruments, Marconi Instruments, Metals Research, and the Ministry of Technology (comprising British Calibration Service, Scientific Instrument Research Association and Summerfield Research Station).



*B.B.C. communications, reject/re-file position with the visual display unit in the centre*

## Computer controlled communications

The B.B.C.'s teleprinter network, which handles the transmission of news items, administrative messages and scripts to and from 60 outstations in London and the regions, has recently been equipped with an automatic switching system incorporating an STC6350 Automatic Data Exchange (ADX). The previous manual system handled more than 700,000 messages a year and was incapable of expansion. In this, incoming messages were perforated on paper tape and transferred to transmitting machines which were connected to the addressee outstations by an operator on a switchboard.

If expansion were possible it still would not have relieved the congestion which occurred at peak periods. Now installed in the Communications Centre at Broadcasting House, the store and forward 6350 ADX provides automatic routing and re-transmitting of messages with a transit time of only milli-seconds. This ensures that the circuits are always operating at their maximum carrying capacity. Stations originating a call do not have to wait until the called station is free before passing their message. Incoming messages are stored until destination lines become available. Designed around a Digital Equipment Corporation PDP-9 processor, the ADX system has a planned capacity for 125 inputs and 125 outputs. The processor is equipped with a fast ferrite core with a capacity of 16,384 18-bit words having a cycle time of 1 $\mu$ s. This is backed up by a Burroughs fixed head magnetic disc store with a capacity of 870,000 18-bit words and an average direct access time of 17ms. Control facilities refer abnormal conditions to one of five supervisory units for action and the system programmes ensure an extremely fast return to service in the event of failure, with full protection for all traffic. One of the supervisory units is a visual display where messages rejected by the ADX because of incorrect routing information in the header can be inspected. The unit has a keyboard

through which the operator may correct the header information and automatically release the message for transmission.

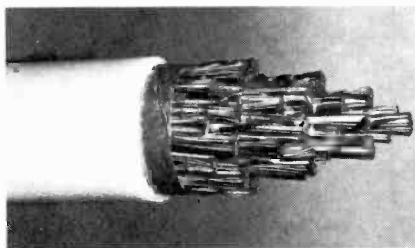
## British exhibit at WESCON

The Electronic Engineering Association is sponsoring participation by 29 U.K. electronics companies at the 1970 Western Electronics Show and Convention (WESCON) which this year takes place in Los Angeles from 25th to 28th August. The British companies taking part are: Air Control Installations (Chard), AEI Semiconductors, Birch-Stolec, Bowthorpe-Hellermann, Ceta Electronics, Cossor Electronics, Culton Instruments, Electrolube, Elite Engineering, Ferranti, FieldTech, GEC-Elliot Process Instruments, Green Electronic & Communication Equipment, Industrial Control Systems, Jermyn Industries, Marconi Instruments, the M-O Valve Company, Mullard, Prosser Scientific Instruments, Racal Instruments, Rank Precision Industries, Research Instruments, Seer TV Surveys, SDC Electronics (Sales), Static Devices, Techne (Cambridge), Vero Electronics, Vision Engineering, and the Wayne Kerr Company.

## Synchronous weather satellite

In response to a request from the American National Aeronautics and Space Administration Hughes Aircraft Company have submitted a design for a synchronous meteorological satellite capable of non-stop operation. The satellite, if accepted by N.A.S.A., will be cylindrical in shape measuring five-feet high by five feet in diameter. All-up weight will be around 450 kg.

The satellite after launch, using a Delta booster with six auxiliary strap-on rocket motors, would be under the control of the Environmental Science Services Administration (ESSA). From the height of 22,300 miles the satellite would take cloud cover



(Above) An 8,000-conductor telephone cable being manufactured at the works of British Insulated Callender's Cables and (left) the finished product. The cable employs "Hyperden" insulation, developed by B.I.C.C., made from cellular polythene 90 $\mu$ m thick giving an increase of 25-pairs-per-cable of a given diameter over earlier methods. The P.O. have successfully laid a length of the cable at Irlam, Lancs.

pictures at the rate of one every twenty minutes, receive information from up to 10,000 sensors (located on ocean buoys, in rivers, on merchant vessels and automatic weather stations), examine solar radiation for high-energy particles and solar X-rays and also measure the earth's magnetic field.

The information received by these means, in addition to photographs, would include temperature, humidity, pressure and water level measurements as well as data on the rate of flow of rivers and streams. All this information would then be transmitted to a ground station for analysis and distribution.

Hughes say that the satellite could be ready for launch eighteen months after the go-ahead was received from N.A.S.A.

## The soldered joint

The International Tin Research Council mention, in their annual report for 1969, work being carried out in response to enquiries received from the electronics industry to assess the integrity of the soldered joint in the light of the demands made upon solder by modern automatic methods of soldering. It would appear that the quality of the solder, which must be very good for use in solder baths, deteriorates during mass soldering because of impurities which dissolve in the bath from the work.

The individual effects of small amounts of zinc, aluminium and phosphorus on the wetting behaviour of a 60/40 tin/lead solder have been studied in some detail. Using a plain resin soldering flux it was found that about 0.005% zinc in the solder began to cause the formation of a visible oxide film. This film could well result in

the solder bridging the gaps between adjacent conductors on printed circuit boards, thus short-circuiting the electrical path. At a zinc content of about 0.01%, dewetting of the solder from a copper surface was manifest and at higher levels still the ability of the solder to spread on the copper was noticeably reduced.

Similar effects were observed when aluminium additions were made to a 60/40 tin/lead solder, but here visible surface oxidation began to occur at a very much lower level (0.0005 to 0.001% aluminium). The deleterious effects of

traces of aluminium appear, however, to be eliminated by the presence of small amounts of antimony in the solder bath. Although phosphorus is less likely to be picked up in solder, it was found that, at phosphorus contents exceeding about 0.01%, the solidified solder deposit had a rough, "gritty" appearance and dewetting began to be apparent.

## Naval battle simulator

A complex military tactical trainer which employs more than £0.5M worth of electronic data display equipment supplied by Marconi Radar Systems has been brought into service at the naval training establishment *H.M.S. Dryad* at Southwick. The trainer was designed by Ferranti working in co-operation with the Admiralty Surface Weapons Establishment and uses three Ferranti computers which drive more than one-hundred A.E.I. type 1400 displays of various sizes. During the course of a particular battle, at any one time, there may be upwards of 200,000 characters displayed on the various screens. The equipment will simulate ships, submarines, aircraft and other weapons, and it will realistically represent radar, sonar, data handling and communications equipments.

Students are accommodated in cubicles each containing at least two plan displays and a separate tabular display. Each cubicle represents a vehicle in the battle and responds realistically to the commands given by the students. Instructors have control of a large number of additional vehicles with which they can inject new circumstances.

A complete photographic record of each exercise is taken for later analysis.

*The Harlech colour television outside broadcast vehicle (right) is equipped with four of the EMI colour television cameras type 2001 and is sub-divided to provide separate control areas for production, sound and vision. The sound facilities provide for 24 inputs into six groups. The vision system allows simultaneous mixing and special effects operation from up to ten inputs and a separate caption scanner.*



# Letters to the Editor

*The Editor does not necessarily endorse opinions expressed by his correspondents*

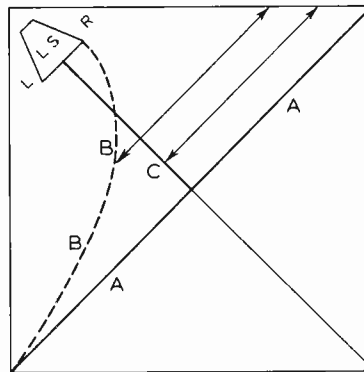
## Low-cost horn

I am glad "Toneburst" has brought into the open in his article in the May issue of *W.W.* the apparent disparity between real and theoretical cut-off frequencies of corner horns. When, some years ago, a home-built horn of mine appeared to cheat by reproducing tones lower than expected, the thoughts indicated below seemed to reconcile fact with theory reasonably well. I offer them, without professional authority, in the hope that confirmation or rejection by those more knowledgeable will help to remedy the absence of any study of the function of the room as a component of the total horn system.

A horn cannot emit frequencies as low as 30Hz unless it has a mouth of about 38ft circumference or 10ft sides if square. If a corner horn reproduces 30Hz then there must exist a mouth very much larger than that which we see, well forward into the room and connected by some kind of flare extension. With a loudspeaker firing diagonally into a square room this mouth will be the rectangle formed on the other diagonal, with dimensions of room diagonal and room height. (In a rectangular room the effective diagonals would be of the square of the shortest wall.) The extension flare formed by floor, walls and ceiling is not ideal, particularly as the ceiling presents a large and abrupt step in one "contour".

This step is mentioned in a later paragraph. For now, note that the listener is either *in* this horn or in a position comparable, in terms of wavelength, with having his ear within a few inches of the mouth of a mid-frequency horn, where the losses and aberrations attributed to mouth and flare are less evident than at more ordinary distances.

Whereas sound from the mouth of an auditorium (e.g., cinema) bass horn is distributed widely, from the effective mouth of a corner horn it is confined, hence there should be some apparent gain which would off-set the shortcomings of the extension flare to some extent. The mouth radiates into an enclosed volume of air (half the room volume for a square room) that is much smaller, and therefore stiffer, than that encountered in any ordinary auditorium. Presented to the cone by horn transformer action this stiffness could be quite considerable and the necessity of some balancing



*A, plane of effective mouth; B, desirable, but unattainable lateral expansion (shown for the right hand only); and C, collision plane, virtual partition limiting lateral expansion of both wavefronts.*

stiffness behind the cone would help to explain the dramatic improvement in bass response noted by "Toneburst" when he fitted a rear pressure chamber. Cone excursion, and therefore distortion, could be expected to be less than in auditorium horns. Is this, I wonder, another reason why the Klipsch horn is so widely acclaimed?

The rectangular wavefronts emerging from the so-called mouths formed between horn cabinet and corner walls are separated, initially, by the width of the cabinet. Lateral expansion brings the inner vertical edges into collision at a vertical plane on the centre-line shown in the sketch. As the colliding edges have equal and opposing energy the collision plane is a virtual partition which prevents further lateral expansion. It forms, with the floor and walls, two flare sections that would limit expansion to something seriously short of the exponential flare-rate (indicated in the sketch) if vertical expansion was also inhibited. However, the top flare "panel" is the ceiling and the required expansion is accommodated.

It is, of course, exceeded, but the ceiling step now seems lossy only to the extent by which its capacity exceeds the volume needed to fulfil the flare rate. Even the remaining capacity may be taken up by the presence (in the horn!) of large furnishings, such as armchairs, at floor level. Whatever its effective volume may be the ceiling step seems comparable with

a leaky flare panel, but the leak is not into unlimited atmosphere. Even in open air an improvised conical megaphone of rolled, unjointed cardboard, or just a single cupped hand—both very leaky horns— are capable of some useful gain.

Despite my admiration of "Toneburst's" experimental effort and design ability, I feel obliged to suggest alternative methods of construction. End-grain butt joints are notoriously weak even with the finest glues, the simple halving joint is far more reliable.

Concrete does not bond with wood; it merely clings, aided in the present case with nail inserts. Effectively we have heavy concrete panels nailed together via sticks. Why, incidentally, if three flare panels must be concrete, should the fourth be wood?

I would use "multi-ply" or blockboard again on the grounds that what's good enough for Klipsch is good enough for me. The panels forming flares, pressure chamber and loudspeaker mounting constitute an array of stiffening webs that impart great rigidity and divide the large panels into smaller areas virtually incapable of flexing, provided a good resin or casein glue is used, with fillets to augment the glue areas.

These observations in no way detract from my admiration of the bold design and experimental effort, against the weight of existing theory, that has provided enthusiasts with a simplified small horn of good performance. My other comments are intended to arouse some responses that may help to explain why it works so well.  
W. GROOME,  
Halesowen,  
Worcs.

## *The designer replies:—*

Mr. Groome's letter is very interesting indeed. In the bass horn I described, the openings in the sides of the rectangular enclosure together provide a cross-sectional area of 260 sq in (130 sq in on each side). Simply placing the enclosure in a corner yields the remarkable results. The important point to note here is that the rate of expansion of the horn outside the enclosure (i.e., the flaring rate made in conjunction with the walls) is too rapid to be accommodated by horn theory for the results attained. Even for a 40-Hz cut-off the cross-sectional area should double in about 16in. An interesting question: when is a horn not a horn? Mr. West (in the June issue) suggests that the air chamber behind the cone turns the enclosure into an infinite baffle type below 100Hz in my design. Yet it is a characteristic of the Klipsch horn that the efficiency is well maintained down to about 40Hz.

Where do we go from here? Perhaps we ought to abandon horn theory as such and get some experimental results on a different track. There is a need for a medium-efficiency loudspeaker that will give corner-horn quality down to at least 20Hz—and that is a good design aim for anyone. The delay-line bass speaker (at present designated "transmission line" following Bailey's article<sup>1</sup>) is rather a non-starter because it offers synthetic bass. Synthetic bass? Synthetic because energy from the rear of the

bass speaker cone is delayed for half a cycle before it emerges to augment the signal from the front of the cone. The signal is thus a blend of the past and the present—but very good on sine waves.

Turning again to Mr. Groome's letter I quite agree with his remark about halving joints—that they are much more reliable than end-grain butt joints—but I have to report no breakages myself.

The use of concrete for the large panel areas and the sides gripping the speaker-mounting board, is to ensure rigidity and thus prevent even the suspicion of hangover. You will certainly get "horn quality" from a well-braced plywood structure but I believe that concrete gives audibly better results, even for the treble horn.

"TONEBURST"

<sup>1</sup> A. R. Bailey, "A Non-resonant Loudspeaker Enclosure Design", *Wireless World*, October 1965.

## Further experience with C-D ignition

I trust that the following practical details of further experience with Mr. Marston's C-D ignition system (January 1970) since my letter in your March issue will be of interest.

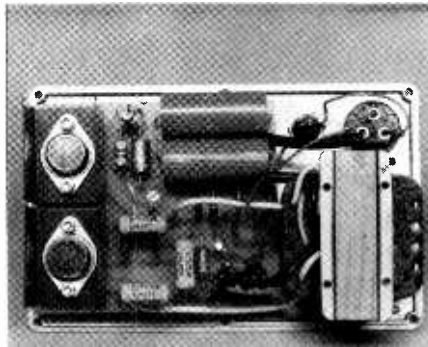
Currently, I have the system fitted to two 6-cylinder cars, one having been recently transferred from a 4-cylinder model. Neither of these cars is in the high-revving class (very few 6-cylinder engines are) and I would say that the Repanco TT51a transformer that I used is quite capable of handling the power required under ordinary road-running conditions. Therefore, for anyone who wishes to build the system without having to reconstruct a transformer, I would unhesitatingly recommend the TT51a for ignition systems up to 6-cylinder capacity. Because of its reduced output, compared with that of Mr. Marston's "bespoke" transformer, I would also suggest that  $R_6$  be dispensed with, also the zener regulating network. Neither of my two systems has these items and there have been no component failures to date. The only other change that I have made to the author's circuit is to make  $R_1 = 100$  ohms instead of 50. The resulting c.b. points current is adequate for keeping the points free of oxide. Good sparking is obtained right down to 5V input from the battery.

The protective resistor in the base of  $Tr_3$  was added to both systems immediately Mr. Marston suggested its inclusion (March letter). In consequence this probably forestalled premature failure of this transistor, as occurred with Mr. Burn's unit.

Needless to say, I am very pleased with the continuing excellent performance and reliability from the C-D system. It performed extremely well during most of the winter period and its cold-starting capability (notwithstanding the reduced h.t. from the TT51a) is outstanding. In this country, it is nowadays not possible for one to explore the undoubted high-performance potential on an

ordinary road-going car (not legally, at any rate) but I have no doubt that for all practical purposes, this system is a very worthwhile addition to any passenger car. Constancy of ignition tune over very long periods is not the least attractive of its many advantages, to say nothing of the improvement in battery life that ought to follow from rapid cold-weather starting.

Perhaps some enterprising transformer manufacturer could be persuaded to offer a commercial version of Mr. Marston's re-wound transformer at a reasonable price.



Mr. Bolton's C-D ignition unit.

The accompanying photograph shows the simple construction of the two C-D ignition systems, on the lid of a lightweight alloy box. The small heat-sinks on the left would appear to refute the suggestion of Mr. J. F. Henderson (March "Letters") that "the power transistors will suffer from excessive heat-dissipation". The only components that run very hot are the bias resistors for the inverter, and  $R_1$ , as is to be expected.

D. E. BOLTON,  
Seaford,  
Sussex.

### The author replies

Mr. Bolton's letter makes very pleasant reading. The only worth-while comment I have to make concerns his elimination of the zener regulating network in the converter circuitry. If these diodes are removed, it is possible that inverter overshoot will cause  $C_1$  to charge way above 400 volts when the ignition is on with the engine stationary; s.c.r. destruction may result. To check against this danger, use a high-impedance ( $20,000 \Omega$ /volt or greater) meter to measure the voltage across the s.c.r. under the above condition; if the voltage greatly exceeds 400, reduce the value of  $R_5$  until the potential is correct:  $R_5$  readily absorbs the surplus overshoot energy that is released when the zener diodes are removed.

Readers may be interested in a progress report on my own C-D unit. This unit has been in constant use for some eighteen months in a 1959 Hillman Minx. It has consistently given very easy starting, even under the severest winter conditions. Acceleration is outstandingly good, and high speed performance is definitely improved. Until recently the car was used

twice each day on a thirty-mile journey, and topped 70 m.p.h. with ease each time.

The most impressive feature of the C-D system, however, is the way in which it improves the life of spark plugs and contact-breaker points, and eliminates the need to adjust them with any precision. My old Minx was exchanged for a 1962 model a few days ago. It had covered a total of 22,000 miles with the C-D system installed, and had not had a single adjustment made to either its spark plugs or c.b. points in all that distance. Before I finally got rid of it, I checked its plug and c.b. gaps. They were 0.060in and 0.008in respectively; their correct values should have been 0.025in. and 0.015in respectively! The vehicle was still running perfectly.

Gadget-minded car owners may like to know that the C-D article is to be included in a book titled "20 Solid-State Projects for Car and Garage" to be published by Butterworths in December.

R. M. MARSTON.

As several of your readers have been complaining of misfiring with the capacitor-discharge ignition system, may I make a point that I had the same trouble whilst experimenting about two years ago with a 600-volt system? I overcame the problem by adjusting the ignition timing as I found that C-D gives a much faster spark.

M. A. SPENCE,  
London S.W.18.

## Symmetry in class B

Far be it from me to cross swords with such a personage as P. J. Baxandall, but I was reading his two-page letter on "Symmetry in Class B" (Sept. 1969) which previously I had only skimmed, when I came across the sentence: "now it is of no fundamental importance which point in a circuit is taken as earth . . .". This is, of course, true, but he then proceeds to 'demonstrate' that the output impedance of his driver transistor ( $Tr_1$  in Fig. 1, a simplified version of his circuit) provides shunt feedback! The fallacy is obvious, since one can discard the 'ideal transistor' and consider a signal current flowing into (or out of) point A—

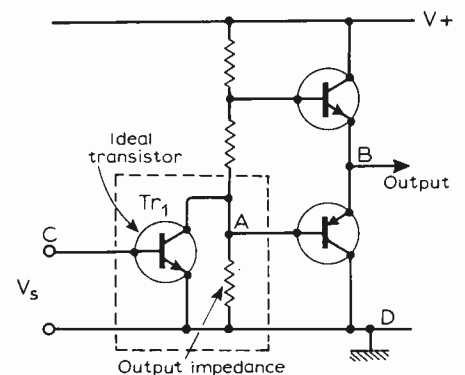


Fig. 1.



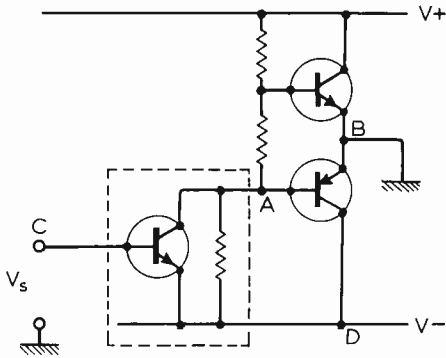


Fig. 2.

the resistor representing the transistor output impedance is simply an additional load on the signal source, and not a feedback element—it is, as he says, non-linear, but the effect is not nearly as bad as he suggests.

Mr. Baxandall's error has arisen because when he earthed point B to simplify the analysis he omitted to 'unearth' his signal source, which meant that he had to disconnect it from the negative line, thus producing a circuit like my Fig. 2, which is not now the same as Fig. 1. Since the signal is applied across B and C instead of C and D. This could be the reason for Mr. Baxandall's circuit requiring extra roll-off components, because now the signal source provides shunt feedback through its own output impedance, which might very well be complex.

I think Mr. Baxandall must at some point have lost sight of the wood for all the trees around, since it is impossible to produce shunt feedback with one resistor earthed at one end, but then, even Homer nods occasionally!

A. H. KING,  
Biggleswade,  
Beds.

### Dynamic range versus ambient noise

Although my article in the April issue (p. 189) was obviously intended and received as a leg pull, nevertheless, as an electronics engineer, self respect demanded that the circuit should indeed work—and work it does! If one deletes  $Tr_{s,10-17}$  and if one makes  $Tr_8$  and  $Tr_9$  2N3055s and  $Tr_{s,5,6,7}$  2N1711s with a 60-volt h.t. line, this circuit will deliver 50 watts into 8 ohms at around the 0.1% t.h.d. mark: other circuit details and voltages being amended as necessary, of course. I have, indeed a lash-up of just such an amplifier, and I have made a pair of 15-W, 15-ohm w.w. resistors, in parallel, glow dull red hot on a sinewave input.

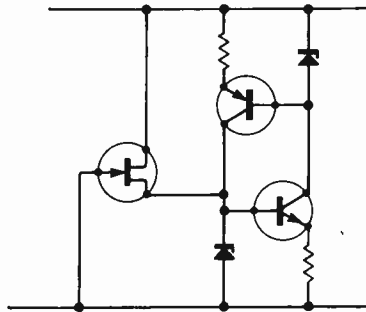
G. I. O'VEERING.

### Self-starting with ring-of-two

In his article "Stabilized Power Supply", April, 1970, Mr. A. J. Ewins discusses the problem of self-starting with the ring-of-two reference circuit. It may be of interest to users of this and related circuits to note a simple method<sup>1</sup> of ensuring self-starting with no loss of regulation against

supply variations. Recognizing the essentially bi-stable nature of the circuit, it is clear that the undesired (non-conducting) state must be suppressed. Thus a component should be added that will not allow the p.d. across either or both of the reference diodes to be zero.

A junction field-effect transistor is included as shown in the diagram. Assume no initial current in the reference circuit. This corresponds to zero gate-source p.d. for the f.e.t. which conducts and drives the reference diode and hence the remainder of the circuit into its desired (conducting) state. If the f.e.t. is not to affect the performance of the reference circuit it must



be cut-off when the circuit is operating normally. As a rough guide the limits of pinch-off voltage that provide self-starting without degrading regulation are given by:— $V_{ref} > V_p > V_{be}$ . Fortunately with  $V_{ref}$  typically ~6V and  $V_p$  ~0.6V the permissible values of  $V_p$  correspond to those for commercially available general purpose f.e.t.s.

P. WILLIAMS,  
Paisley College of Technology

1. "Self-starting of voltage Reference Circuits", Proc. I.E.E.E., Nov. 1969, p.2078.

### One-transistor voltmeter

In "Letters to the Editor" (March issue) F.P. Mason describes a one-transistor voltmeter that he invented and patented.

This uses the principle of a meter with rectifiers in a feedback path. It is not clear whether he realized (it does not affect the patent) that this principle was not new.

The writer used it for two- and three-valve meters in 1954 and does not claim to have invented it. (With feedback to the first cathode the input impedance can be kept high.)

In an article in the December 1969 issue G. W. Short gives a detailed account of how to design this type of one-transistor meter.

Unfortunately he misses out two important points, and appears to make a minor error.

Assuming a sinusoidal input voltage, the meter current will have a rectified sine waveform.

Let  $I_m$  be the peak value of this.

For 5 times peak current  $5I_m r_m + 2V_f = V_{CB}$  surely, not  $V_{CE}$  as in the article, where subtraction is done to find  $V_{CB}$ . This affects four equations.

Point One. The meter deflection is due to a current  $I_{\phi}$  say, which is the average of the meter current.  $I_m = (\pi/2)I_{\phi}$ .

Point Two. Ohm's Law is used to find the

value of  $R_M$  the input resistor. As  $V_{in}$  (f.s.d.) is an r.m.s. value so must be the meter current, say  $I_r = I_m/\sqrt{2} = (\pi/2\sqrt{2})I_{\phi} = 1.111I_{\phi}$ .

1.111 is the form factor and reduces  $R_M$  by 10%.

The peaks, for which Mr. Short makes allowance, are averaged in the meter reading.

The writer had designed a simple companion meter to measure the highest and lowest peak levels. This meter will also measure the two levels in square waveforms.

D. L. CLAY,  
Coventry,  
Warwicks.

G. W. Short replies:

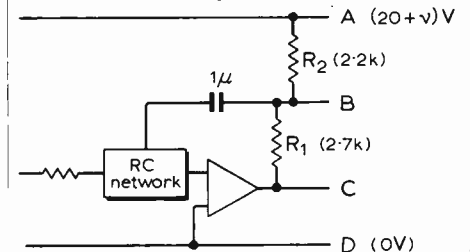
The design formula for  $V_{CE}$  is intended to yield a practical value rather than state an absolute truth. While the value of the alternating base-emitter voltage should strictly be added it is only a few tens of millivolts and so is not worth bothering about. For similar reasons the design formula ignores the effect of the collector saturation voltage. Anyone who wants to play safe should add 1V to the calculated value of  $V_{CE}$ .

The design procedure did not in fact specify that  $V_{in}$  is an r.m.s. value. It would have been clearer to have done so, and adjusted  $R_M$  by a factor of 0.9. Step (5) should therefore be altered to read:  $R_M = 0.9V_{in\ rms}/I_m$

### Theoretical and measured response

I read with interest Mr. P. M. Quilter's comments in the April issue on the tone control circuit of Dr. A. R. Bailey's pre-amplifier. I should like to add some comments of my own concerning the feedback attenuator  $R_1$  and  $R_2$ .

A small ripple voltage  $v$  is present at the +20V supply A. To a first approximation the response of the system to this ripple voltage is that of an operational amplifier with input resistance  $R_2$  and feedback resistance  $R_1$ . It follows that the



ripple voltage at point C is  $-\frac{R_1}{R_2}v$  and

that the point B is a virtual earth with respect to this signal. Thus if the output is taken from B instead of C a dramatic reduction in background noise results, at the expense of a 50% reduction in gain. A similar effect would be given (with increased tone control range as pointed out by Mr. Quilter) by taking the feedback from point C instead of B.

G. J. BIGNOLD,  
Worcester Park,  
Surrey.

# Sinusoidal Oscillator for High Temperatures

by P. Williams\*

The Wien bridge oscillator circuit has a reputation for providing a sine wave free from harmonics, hum and noise. Conventional circuit design uses a high-gain amplifier with the frequency determining CR elements in the positive feedback 'half-bridge' arm and a thermistor or other temperature sensitive resistor element in the negative feedback arm of the bridge<sup>1</sup>. Such an arrangement automatically maintains the oscillator output constant by adjusting the negative feedback. This technique, which does not use a non-linear circuit element (the thermistor resistance changes only slowly, being constant during one cycle of oscillation), has been shown<sup>2</sup> greatly to improve the frequency stability.

Unfortunately the use of a temperature sensitive element in this way only maintains constant output amplitude independent of the ambient temperature if the element temperature is a good deal higher than ambient. Use of a thermistor is thus not usually practical above about 40°C. In the course of some industrial instrumentation circuit development the need arose for an oscillator to provide a constant amplitude

sine output at temperatures up to 70°C, with good frequency stability. The circuit shown was developed to meet this need. It provides a sine output of 1 V r.m.s. swinging symmetrically about the earth line.  $C_1$ ,  $R_1$  and  $C_2$ ,  $R_2$  are the frequency determining elements of a Wien half-bridge (values shown are for 5 kHz). They provide frequency selective positive feedback from the output of the amplifier system, comprising the 701C integrated circuit and  $Tr_2$ , to the non-inverting (positive) input terminal of the 701C. The junction field effect transistors  $Tr_1$  and  $Tr_3$  and resistors  $R_9$ ,  $R_{10}$  constitute a resistive attenuator circuit half-bridge providing negative feedback to the inverting input terminal of the 701C amplifier. The drain-source resistance of  $Tr_1$  is increased, to the value which provides constant amplitude sinusoidal output, by the negative bias on its gate, derived from the rectified output of  $Tr_2$ . The potentiometer  $R_{11}$  enables the resistance of  $Tr_3$  to be set to a suitable value for control of  $Tr_1$ . The fixed resistors  $R_9$  and  $R_{10}$  ensure linear operation by reducing the amplitude of the sine input to  $Tr_1$  and  $Tr_3$  to a value well below the pinch off voltage of these transistors. Although the drain-source resistance

Operating frequency	Value of $C_1$ , $C_2$	Value of $R_1$ , $R_2$
20 Hz	0.068 $\mu$ F polyester (with 0.022 $\mu$ F shunting gate of $Tr_1$ to earth)	120 k $\Omega$ $\pm$ 5%
500 Hz	0.0027 $\mu$ F silver mica	120 k $\Omega$
5 kHz	0.0027 $\mu$ F silver mica	12 k $\Omega$
25 kHz	500pF silver mica	12 k $\Omega$
70 kHz	120pF silver mica	12 k $\Omega$
		(all 'Histab')

Table of variable components.

of both  $Tr_1$  and  $Tr_3$  falls with temperature, the ratio of the two drain-source resistances (and hence the feedback factor) remains approximately constant. In practice a change in temperature from 25° to 70°C produced amplitude changes of about 2% and a frequency change of less than 2%. Operation at frequencies over the range 20 Hz to 70 kHz has been achieved by suitable choice of capacitors  $C_1$  and  $C_2$  and resistors  $R_1$  and  $R_2$  as shown in the table. At frequencies below 50 Hz a 0.02  $\mu$ F capacitor was connected between the gate of  $Tr_1$  and the earth line to prevent "squegging" (modulated oscillations).

## REFERENCES

- Hickmann, D. E. D., "Wien Bridge Oscillators", *Wireless World*, Dec. 1959.
- Bailey, A. R., *Electronic Technology*, vol. 37, p. 64.

## Holograms on metal film

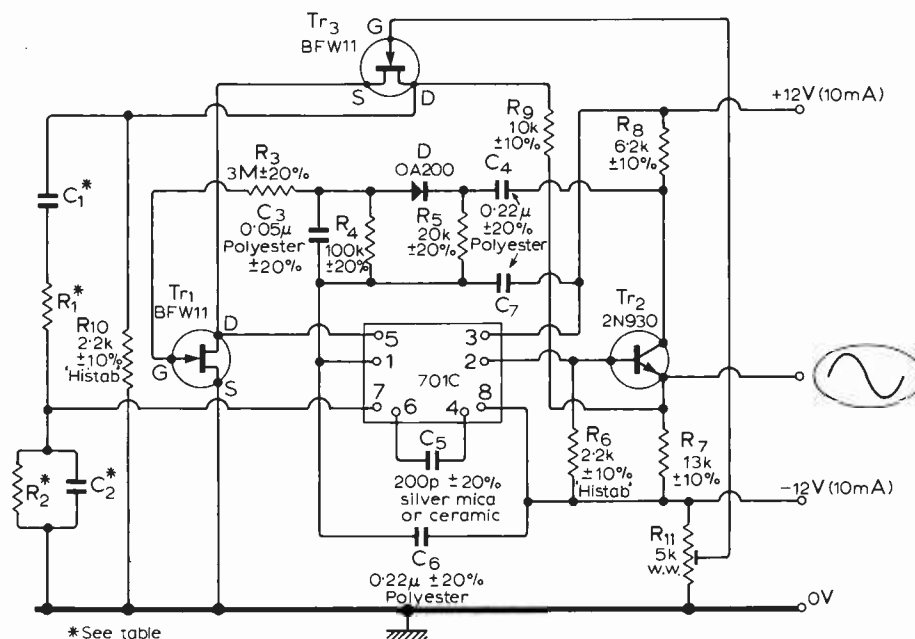
Very thin films of metal—bismuth, tellurium, aluminium or gold—deposited on a sheet of glass have been used by R.C.A. engineers in America as an alternative to photographic plates for storing holograms. The resolution obtained is about the same as using photographic methods—more than 1000 lines per mm—but the exposure time is reduced to between 5 and 20 nanoseconds. This means that the extremely stable platform, needed to support the subject during photography to prevent movement and subsequent hologram distortion, can be dispensed with due to the very short exposure time.

The light from a pulsed laser is split into two beams, one of these, the reference, is directed on to the metal film, the other reaches the metal film via the object of which the hologram is to be made. At those points where the two beams interfere constructively (add) the laser light is converted into heat which evaporates the metal film. Where the two beams interfere destructively (cancel out) nothing happens.

No further processing is required and the hologram can be viewed at once without moving the film in any way. This means that the hologram is perfectly positioned for the successive observations required in industrial non-destructive testing of materials and products.

For computer memory applications a glass plate coated in a metal film measuring only 400  $\times$  110mm could store 300 million bits of information.

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Temperature stable oscillator circuit employing a bipolar transistor, two f.e.t.s and an i.c.

# The Unijunction Transistor

## A close look at its behaviour and a guide to its use

by O. Greiter

The design of electronic circuits is considered, if anyone actually turns his mind to this aspect, to be a calm, logical process. Sometimes, however, if you examine the matter calmly and logically, you get a feeling that whim and fashion play a very great part. Some circuits and some devices seem to be particularly sensitive to this favourite son approach. Oscillator circuits are the subject of unending debates. The unijunction transistor is a device which has, I think, been overlooked by many engineers who could use it to advantage. One indication is that, so far as anyone remembers, *Wireless World* has never published an article on unijunctions, and has shown very few circuits containing them. And not everyone can afford to read all the American journals.

It is not as though it were some new-fangled device: it is not as though it were an expensive device. The pound in your pocket will still buy you a couple of unijunctions and a short ride on the underground. The first devices appeared in 1953, and the silicon version in 1956. Changes in manufacturing technique, and the normal time lags before the line began to run, suggest that as a cheap simple device the unijunction has been with us for just about a decade.

The essential function of a unijunction transistor is that it is a voltage sensing device. Used with a CR circuit it becomes a timing circuit and also, because of its re-setting behaviour, an oscillator. We shall see that the circuits are extraordinarily simple in form.

We must begin by examining the construction of the device itself and its characteristics. The structure shown in Fig. 1(a) is very convenient for those of us who want to understand the device. A small rod of n-type silicon has ohmic, that is non-rectifying, contacts applied to each end. Near the middle an aluminium wire is used to generate and connect a small p-type region. And that is all. At least that is all that really concerns us. Down at the plant they do not like fiddling about at the ends of long narrow rods and two more practical structures have been devised. These are shown as Figs. 1(b) and 1(c). They are known as the bar structure and the cube structure. The characteristics are slightly different, but we can hardly discuss this until we know what the terms we must use mean.

The structure of Fig. 1(a) looks exactly like the basic structure of the field effect transistor and the reader may wonder if new unijunction is but old f.e.t. writ large. In fact it is surprising how totally unlike each other the two devices are, at least when operated at their design biases. I confess to being too lazy to test whether one could persuade either device to operate in the mode appropriate to the other. There is some interest in this, however, as it suggests a way in which one might get very odd effects in a field effect transistor circuit with excessive input.

If we are to understand the unijunction transistor behaviour we must begin with an

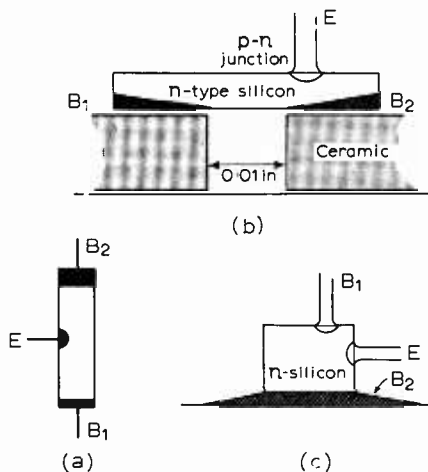


Fig. 1. (a) The early construction technique, with two ohmic connections to an n-type silicon rod and a small p-n emitter junction. (b) The bar structure. (c) The cube structure.

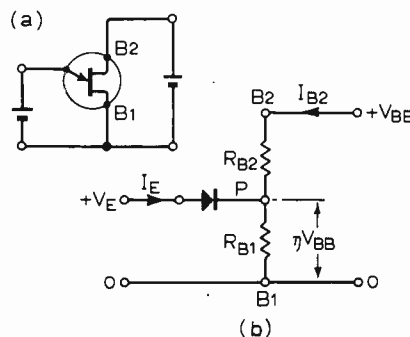


Fig. 2. Circuit and equivalent.

equivalent circuit. It is convenient to introduce at the same time the standard symbol. This is done in Fig. 2. The total resistance between B2 and B1,  $R_{BB} = R_{B1} + R_{B2}$ , is called the interbase resistance. As the two end contacts are ohmic constants, this is just the resistance of the rod of silicon, in the simplified structure. It is about 5-10 thousand ohms. Normally we operate unijunctions at about 10-20 volts, so that the base current will be about 2 mA. It is useful to keep this figure in mind when looking at circuits with additional resistance in series with one or both base connections. At this stage the emitter is assumed to be left open.

The device is just a rod of resistive material, so the point P in Fig. 2(b) will be at a voltage of  $(R_{B1}/R_{BB})V_{BB}$ . This ratio,  $(R_{B1}/R_{BB})$ , is settled by the geometry, the mechanical construction, and it is known as the stand-off ratio, denoted by the symbol  $\eta$ . A typical value of  $\eta$  might be 0.6, with a range which depends on how well the mechanical tolerances can be held. So far as we are concerned, the tolerances appear in a sorting operation and if you want a tight tolerance you pay for a hand-picked specimen.

We may now apply the battery to the emitter terminal. So long as  $V_E < \eta V_{BB}$  the diode shown in Fig. 2(b) will be reverse-biased, and no emitter current will flow. No current is an abstraction here, because there will be a small leakage current, typically 2 microamps, which is not enough to disturb the voltage at P. This current can be significant in some circuits.

As we increase  $V_E$  the diode becomes forward biased and will pass current from  $V_E$  into the bar. This current consists of holes emitted into the silicon, and these holes drift from the emitter to base one. The presence of these holes causes the number of electrons in the lower half of the bar to increase. The conductivity of this part of the bar increases, so that  $R_{B1}$  becomes smaller. Typically, if  $R_{B1}$  is 4500 ohms with no emitter current it will fall to 2000 ohms for one milliamp of emitter current, and to 100 ohms for 20 mA. Let us assume we have  $V_{BB} = 20$  volts and  $\eta = 0.6$ . When  $V_E$  goes to just over 12 volts, so that we get our  $I_E = 1$  mA, the value of  $R_{B1}$  drops to 2000 ohms, and as  $R_{B2}$  is 3000 ohms the voltage at P falls to 8 volts. Immediately  $I_E$  shoots up, making  $R_{B1}$  get even smaller and the forward bias on the

diode get even larger. If we were foolish enough to use this test circuit the current would rise until the transistor burnt out.

In all simplified pictures there are defects. By this account, even one hole passed from the emitter into the bar should start the proceedings. Of course this is not true. The current needed is, however, extremely small, and a rough value can be taken as one microamp. This current is called the peak point current,  $I_p$ .

Another simplification which can cause trouble is that although the holes injected at the emitter should all be drawn towards base one by the field produced by  $V_{BB}$ , this just does not happen in the practical structures. Some drift off into the  $R_{B2}$  region, hotly followed by their electrons. In consequence  $R_{B2}$  drops a little and the current  $I_{B2}$  increases by more than one would expect. It is necessary to bear this in mind if the overall circuit is one in which there may be excessive power dissipation at the peaks.

Once the triggering action has taken place the emitter-base one circuit is just that of a rather resistive diode. We need an overall device characteristic, or set of characteristics. The most important group is the static emitter characteristics, which are typified by the curve in Fig. 3. From this it can be seen how the current increases quite normally as the emitter voltage is increased from  $V_0$  to  $V_p$ : below  $V_0$  the diode leakage current is flowing out at the emitter, of course. When the peak point is reached, however, the current can increase without the voltage increasing, and we have a region of negative resistance down to the valley point. A rough guide figure for this point is that it corresponds to an emitter current of 4mA at  $V_0 = 2V$ . Of course it varies from type to type of unijunction, and depends to some extent on the overall working level, as defined by  $V_{BB}$ .

Beyond the valley point the characteristic shows the normal positive resistance of the emitter-base one diode. In drawing these typical characteristics one gives this a reasonable slope so that the valley point

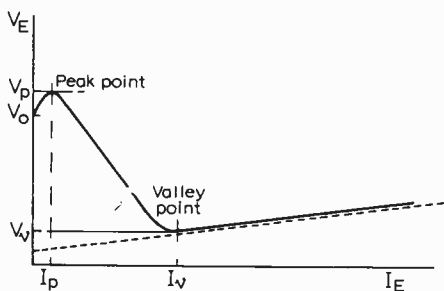


Fig. 3. General static emitter characteristic.

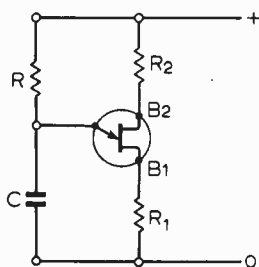


Fig. 4. Circuit of relaxation oscillator.

shows up nicely. Peering closely at some real characteristics the resistance in this region looks as though it might be down as low as 10 ohms, or even lower. It is possible to get very high peak emitter currents: it is essential to make sure that you do not get destructive values of  $I^2t$ .

The commonest use of unijunction transistors is probably in relaxation oscillators. A complete circuit is shown in Fig. 4, and includes two resistors which are not vital to its operation.  $R_1$  has the advantage of limiting the emitter-base one current as well as providing a voltage pulse at  $B1$ . We will discuss  $R_2$  later. What happens when we connect the battery to this circuit? On switch-on, the capacitor is not charged, so that  $V_E$  is zero. The odd milliamp flows from  $B2$  to  $B1$ , establishing the bias in the diode of the equivalent circuit.  $C$  is charged steadily through  $R$  until the capacitor voltage reaches the value of  $V_p$  for the particular conditions. The triggering action now takes place, discharging  $C$  down to about 2 volts. If all is well, this is where we started, and away we go again. All is only well, however, if the value of  $R$  is suitable. Let us draw the characteristic in the form we adopt for other devices. This has been done in the S-shaped curve of Fig. 5. A load line corresponding to a resistance  $R$  joins the point  $V = V_{BB}$  to  $I = V_{BB}/R$ . It intersects the device curve at the point  $P$ , where the resistance is negative. In drawing the S-curve the upper part has been flattened out to keep the scale of the drawing more convenient, for reasons which will become obvious.

A formal discussion must take into account the effect of the capacitor. When the supply is first connected the capacitor holds no charge, and thus  $V_E$  must be zero. The working point moves from  $B$  towards  $D$  as the capacitor is charged through  $R$ , and virtually no current flows in the unijunction emitter. At  $A$ , where the peak point current is flowing, we have a situation where  $V_E$  wishes to rise above  $V_p$ , but for very small time increments is held constant by the capacitor. The only point of the device characteristic at which we have  $V_E = V_p + \delta$  is the point  $B$ . The circuit triggers and a relatively large current begins to flow. Most of this is supplied by the capacitor, and  $V_E$  decreases, with the device working point moving down from  $B$  towards  $C$ . Finite times may make the triggering follow the broken line to a point between  $B$  and  $C$ , but the general effect is the same. The slope of  $BC$  is in practice that of a fairly small resistance, so that the capacitor discharges very quickly. At  $C$  we reach the valley point. Obviously  $V_E$  cannot increase rapidly, because the capacitor will see to that. The current  $I_0$  cannot be provided by the resistor alone. The only point on the device characteristic which is accessible is  $D$ : the device cuts off. And from  $D$  there is nowhere to go but  $A$ .

The emitter voltage is the sawtooth shown in Fig. 6(a). One current pulse is shown in some detail as Fig. 6(b). This is not the waveform which one observes, because the actual transitions are dominated either by the way the charge concentration builds up or by the circuit strays. The pulse looks,

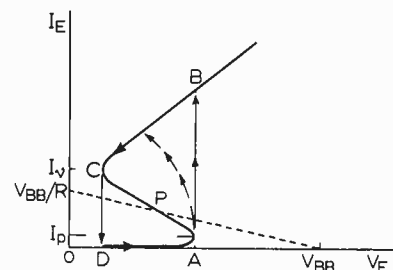


Fig. 5. Trajectory of emitter conditions in relaxation oscillator.

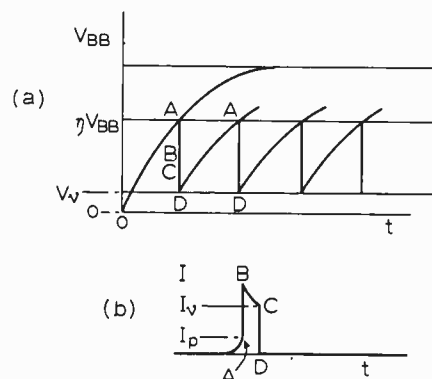


Fig. 6. The emitter voltage (a) as a function of time and the current (b) on a greatly expanded scale.

in practice, pulse-shaped. We usually look at the current pulse across the resistance  $R_1$  in the circuit of Fig. 4. It is a nice clean pulse, conveniently referred to the negative line. We can, however, put a small value of resistance in series with the capacitance, although we may then have problems with the pedestal produced by the capacitor charging current.

A reasonable approximation to the oscillation frequency is obtained by using the time taken for the path  $OA$  and neglecting the other terms. This gives us

$$t = CR \log [1/(1-\eta)].$$

If we are lucky enough to get a unit with an  $\eta$  of 0.63, this reduces simply to

$$t = CR, \quad f = 1/CR.$$

When we use the cheaper, wide-tolerance, unijunction we can assume this as a likely centre value, giving us a very quick way of choosing the typical size of component we shall need. For most circuits it is safe to say that  $R$  will lie between  $10^4$  and  $10^6$  ohms. Typical values of  $C$  range from 0.01  $\mu F$  to 1.0  $\mu F$ , offering a frequency range of 1 Hz to 10,000 Hz.

This has been, of course, a rather oversimplified picture, but for many applications it is actually sufficient. The circuit of Fig. 4, without  $R_1$  and  $R_2$ , provides an oscillator which is stable for small changes of voltage and temperature to better than 1%. It is easily the cheapest way of getting this sort of result provided that the waveform is acceptable. Improved performance is, however, usually wasted sooner or later, and here the two resistors enter the circuit. We must consider them separately, beginning with the dull one,  $R_1$ .

The main effect of the resistor added externally in the base-one lead is to change

the shape and position of the valley. It is not precisely correct to say that we simply add a term  $I_E R_1$  to the voltage  $V_E$  in the curve of Fig. 3. The current which flows out of B1 is bigger than  $I_E$ , because of the fall in the value of  $R_{BB}$ . Qualitatively, however, this describes what happens. The curve beyond the valley point is rotated upwards, moving the valley point up and to the left. Practical circuits use small values of  $R_1$ , which do not have very much effect. Typical values are between 15 ohms and 47 ohms and they control the amount you can get out of the circuit much more than they control its oscillation characteristic.

The base-two resistor,  $R_2$ , is much more interesting. Looking back at Fig. 2(b) we see that in strict truth the emitter voltage at which the unijunction will trigger is given by

$$V_E = \eta V_{BB} + V_D$$

where  $V_D$  is the drop across the diode junction produced by the flow of the peak point current. This voltage, about half-a-volt, is naturally much lower for the high-sensitivity devices than it is for those which have a high value of peak point currents. And the peak point current, from a handy list of characteristics, ranges from 2 microamps to 25 microamps, according to one type of unijunction. Regarded purely as a diode we might expect that the voltage  $V_D$  would change 2 mV per °C. For a typical circuit this would correspond to about  $2/10^4$  of the voltage excursion, giving a frequency shift of  $1/10^3$  for a 5°C change of temperature. This stability figure is much better than we actually obtain, so other effects must be at work. One of these, especially for the cube structure, is the temperature variation of  $\eta$ . For the bar structure this is said to be negligible, and  $V_D$  is given the blame. The reader may feel, as I did, that this just does not make sense. In fact, although the resistance  $R_{BB}$  does not appear in the expression we have written for  $V_E$ , it is the real thing in the wood-pile (and sucks to the Race Relations Board).  $R_{BB}$  creeps in because, as the resistance of a lump of semiconductor, it varies quite a lot with temperature. In fact the variation is very nearly 1% per °C. This does not affect  $\eta$  very much, and we can see that in the bar structure  $\eta$  is settled by very simple geometry indeed. It does, however, alter the number of charge carriers normally in the semiconductor and it seems fairly obvious that this will in turn alter the number of carriers injected at the emitter which are needed to disturb the flow. This is what we find. For a rise in temperature of 100°C the interbase current is halved, and the peak point current is also halved. This smaller peak point current is produced, of course, by a smaller excess voltage. In fact the value of  $V_D$  is not as one is tempted to think, the voltage across the diode for a fixed current, but rather the voltage for a current which is itself temperature-dependent.

One rather pleasant surprise is that  $R_{BB}$  has a conductor-like behaviour, with a roughly constant temperature coefficient. If we do the mathematics we find that we can get quite good compensation by using the right value of  $R_2$ . As the temperature rises and the interbase current falls, the

voltage at B2 will increase by a factor of  $\Delta I R_2$ . This tends to balance out the drop in  $V_D$ . Notice how the sensing is done by  $R_{BB}$ , the very factor which causes the change.

This is by no means the full story. It is, however, the first approximation to the story, and we can now quote the value of  $R_2$  which should give perfect compensation:

$$R_2 = \frac{0.7 R_{BB}}{\eta V_1}$$

Typically  $R_{BB} = 7000$  and  $\eta V_1 = 10$

(notice that 0.7 is a voltage)

$$R_2 = 500.$$

A correction is needed when we include  $R_1$  in the circuit, because  $R_1$  is an anti-correction term. We must add a factor  $R_1(1-\eta)/\eta$ , or about  $R_1/2$ . But if  $R_1$  is 50 ohms, this gives us only a change of 5% in  $R_2$ . Round up to 510, rather than down to 470. And only in the electronics industry would anyone round up 500 to 510.

Without temperature compensation a typical figure for the change in frequency with unijunction temperature is between 3% and 6% for 100°C. This is 300-600 p.p.m./°C.

However, the capacitor and the resistor will also be changing in value. At temperatures above 20°C a metallized polycarbonate capacitor will have a temperature coefficient of 100 p.p.m./°C and a metal film resistor a temperature coefficient of 50 p.p.m./°C. As both of these are positive, the frequency will fall by 150 p.p.m./°C. Provided that the whole circuit is kept at the same temperature we need only somewhere between  $\frac{1}{2}$  and  $\frac{3}{4}$  of the predicted compensation.

The net result is that we should not have to work too hard to get a stability of 100 p.p.m./°C. To do a bit better than this we must measure the values of  $\eta$  and  $R_{BB}$  for the individual device, rather than just paying a bit more for the close tolerance type. A really cheap unijunction transistor has a range of  $R_{BB}/\eta$  of about 3:1 according to the specification sheet, while the more expensive ones are within a range of about 1.7:1. This means that an average correction could be about 10% in error, which is really better than we know what we are correcting.

The high class thing to do is to temperature-cycle the whole oscillator. If you are sure of the capacitor and resistor you can

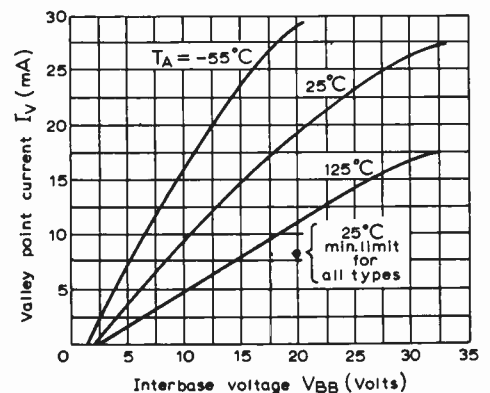
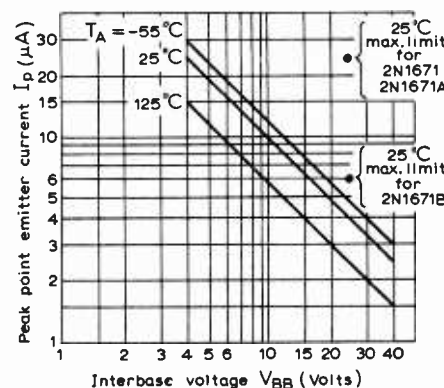
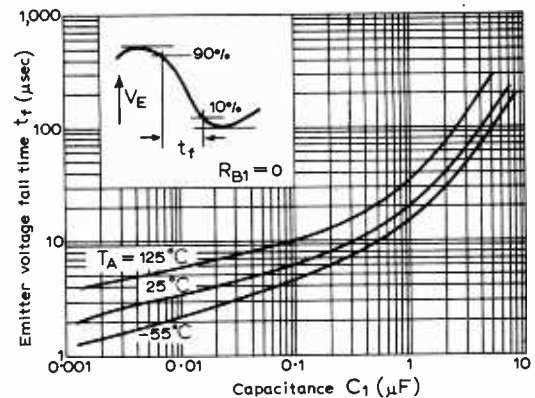
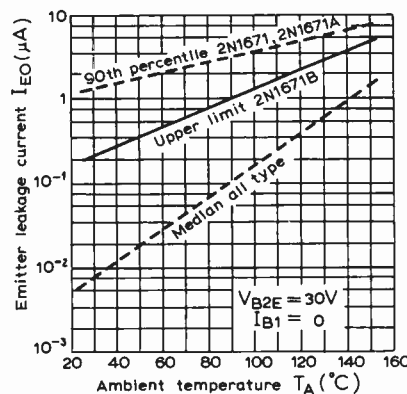
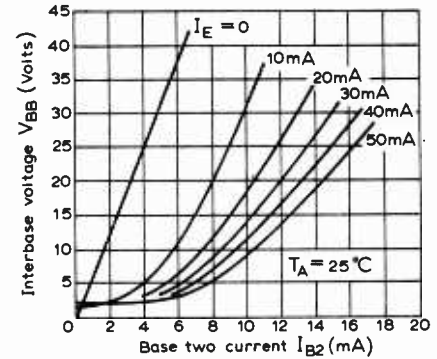
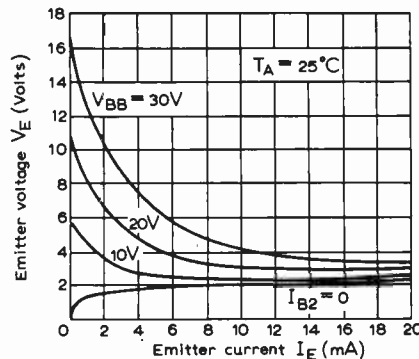


Fig. 7 Data on the General Electric 2N1671. unijunction transistor.

just cycle the unijunction, which is a very fast operation, and trim  $R_2$  to give the theoretically derived positive temperature coefficient. To be sure the capacitor is really warmed up you need a lot of time, and a lot of justification. If you do embark on this path you find that these temperature coefficients you are balancing so nicely are not, in fact, constants. The unijunction is less sensitive at low temperatures, the capacitance is more sensitive if you use the type of polycarbonate unit whose characteristic I quoted. Overall the shape can be called parabolic, the frequency rising at both extremes. It is claimed that one can get 10 p.p.m./°C for a reasonable temperature range around the minimum.

Meanwhile, back in the system, how constant is the supply voltage? Typical for the dependence of frequency on voltage is a figure of 2 parts per thousand for a 10% change in supply voltage, or 200 p.p.m./1% voltage change. When we start talking about 10 p.p.m. per °C we are also talking about supplies which are holding to 0.05% per °C and per everything else. It is found that  $R_2$  also controls the variation with supply voltage, but the value of  $R_2$  needed to give good stabilization against voltage changes is somewhere between 30% and 50% of that needed to stabilize against unijunction changes alone. We have already seen that we do not need this full stabilization, because the capacitor and the resistor are providing some compensation. This, indeed, is one of the things which makes this very simple circuit so pleasant to use. For once, it would appear, nature is on your side.

There are, as always, cunning techniques for using diodes in  $R_2$ , and other odd balancing elements, which will shape the overall temperature coefficient. This is a specialist area and before you start on it you need to go through the full analysis in detail. My own feeling is that for a general purpose oscillator you will not go far wrong if you pick  $R_2 = 220$  or 270 ohms, and that it might be cheaper to stick the whole thing in a temperature controlled case instead of fine-tuning every unit. Roll on the days of cheap nuclear min-power, so that we can keep the thermostat system working day and night and avoid waiting for things to settle down—settle up, perhaps, would be more appropriate.

Two additional factors must now be taken into account. In the discussion of the oscillator circuit we took it for granted that only the charging time of the capacitor needed to be considered. For an oscillator operating at 1000 Hz we might conveniently use a 0.1  $\mu$ F capacitor. It is found that the fall time of such a capacitance ranges from 5 microseconds to 10 microseconds as the temperature increases from 25°C to 125°C. This is a change of -50 p.p.m./°C in oscillation frequency. This fall time depends on the capacitance, but is not directly proportional to it. It also depends on the value of  $R_1$ , as you might expect.

The second factor is the ease with which the circuit may be triggered. We have seen that the triggering occurs when the emitter voltage reaches, roughly,  $\eta V_{BB}$ . This is equivalent to saying that

$$V_{BB} = V_E/\eta$$

Assume that the circuit is oscillating at 1000 Hz. It takes 1000 microseconds for  $V_E$  to run up to the triggering point. Assume also a linear rise, with  $V_{BB} = 20V$ . The instantaneous value of  $V_{BB}$  at which triggering can occur is then rising at the rate of 20 millivolts per microsecond. If a noise pulse of 20 mV appears on the supply line just one microsecond before triggering is due, the triggering will occur after 999  $\mu$ s, and the frequency will be  $1/10^3$  in error. Notice that the RC circuit protects  $V_E$  from this pulse. We must watch for the danger of synchronization, or partial synchronization, to noise or ripple. It will be noted that we are more likely to get a nuisance effect with a system of low target efficiency, running from a roughly smoothed supply.

than a frequency shift in a system of high design stability, in which there will be a voltage regulator which should also keep down the noise and ripple.

The circuit applications of the unijunction transistor, which are by no means limited to the production of pulses and saw-teeth, must be left to another article. It is, however, desirable to provide some typical characteristics of an actual unit, as distinct from the stylized characteristic used to explain the working. Fig. 7 consists of a selection of the material contained in the data sheet for the General Electric 2N1671 family. It must be added that almost all the material published on the unijunction and its uses appears to originate with General Electric.

## Crossword

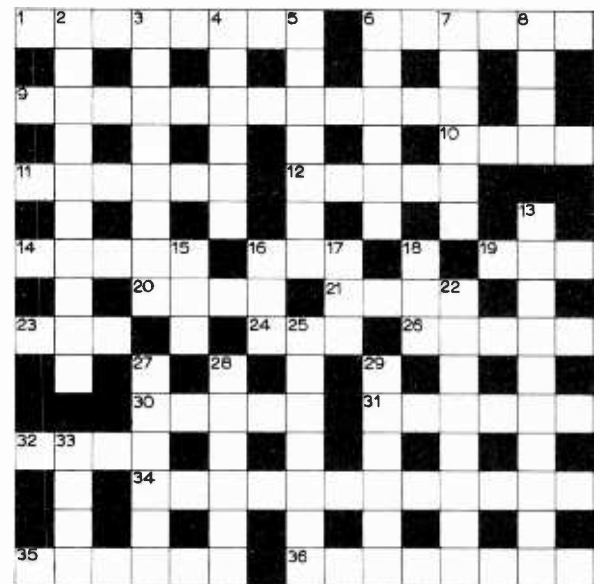
compiled by P. R. Lloyd

### Across

1. Waveband crept somehow in addition. (8)
6. Group containing one bit used for checking. (6)
9. Wild mice run after a Greek having letters and numbers. (12)
10. It has no meshes in the middle of the street. (4)
11. A cubic metre with nothing for realistic reproduction. (6)
12. A measure of magnetic flux density in a ferrite slab. (5)
14. Turn English book back. (5)
16. Measure inductance the French returned? (3)
19. Lorry ignition features a ferrite. (3)
20. A resonant circuit of military application? (4)
21. Half the alphabet is something very small. (4)
23. A resistor capacitor discharge. (3)
24. Work using epoxy resin glue initially. (3)
26. Music channels? (5)
30. We would set about infra-red with connections made. (5)
31. One in the class is a mastermind. (6)
32. Penultimate letter to a service-man brings an aerial. (4)
34. Circuit parameter meant cos distribution in colour. (4,8)
35. A course so backward it engenders pity. (6)
36. Fill small room used in weighing. (4,4)

### Down

2. Fliers must have grounds for starting discharge. (5,5)
3. Company with gas to hire like a laser beam. (8)



4. Uncontrolled, melted half the domain. (6)
5. Good material for the screen! (7)
6. He raps out a set of notes. (6)
7. Electric talk can show at the corners of the mouth. (6)
8. Half of it to copy for recording perhaps. (4)
13. It's useful in aerodynamics to twist and penetrate the barrier. (4-6)
15. An organ in the middle of the heart. (3)
16. Two-way supplement. (3)
17. Cover with an insulator—not lead! (3)
18. There's nothing in the side-band. Gasp! (3)
22. Attractive enchantment surrounds land. (8)
25. Primitive artist I'd back with about a pound. (7)
27. On-off device possibly faulty with short circuit. (6)
28. Same rf alignment gives unit pictures. (6)
29. Order paper from an aged organization. (6)
33. A piece of ground 100 square metres plus one. (4)

Solution on page 338

# A Simple Op. Amp.

## A design intended to make life easier for the newcomer to operational amplifier techniques

by D. Griffiths, Ph.D.

Grappling with my first practical use of operational amplifier integrated circuits, my upbringing on discrete component circuitry made me want to have a simplified picture of what was going on inside the little packages. Of course, the circuit did just what the manufacturer said it would with given external connections and there was the astoundingly complex equivalent circuit to gaze at. To get a feel of what was going on, I found it a great help to play around with the simple circuit of Fig. 1. While it correctly demonstrates op. amp. characteristics, it has a poor d.c. performance and a curtailed h.f. response, with the closed loop gain being 3dB down at typically 0.5 to 1 MHz. On the other hand, over the audio frequency band it can show a noise figure of below 2dB and has less than 0.75% harmonic distortion at 1 kHz with 1 V r.m.s. output before feedback is applied.

The "follower with gain" mode of operation is of wide application and is achieved by the type of connection shown in Fig. 2. Here  $Tr_2$  acts as an emitter follower causing the emitter of  $Tr_1$  to follow closely the signal from the feedback network. If the amplifier gain is sufficiently large, the base voltage of  $Tr_2$  accurately follows that on the emitter of  $Tr_1$ , since only a very small differential input is necessary to develop an output voltage. This gives a high input impedance and constrains the voltage output to  $(R_1 + R_2)/R_1$  times that of the input to  $Tr_1$ . The decoupling capacitor shown dotted (Fig. 2.) can remove the a.c. feedback and enable the open loop a.c. performance to be assessed while still retaining d.c. stabilization of the operating points.

The input transistors are run at a collector current of just under 100  $\mu$ A each; the resulting 200  $\mu$ A or so through  $R_4$  generates the necessary tail voltage of just under 9 V. Decreasing the collector currents would reduce the input biasing current drain but would also lead to decreased gain and frequency response. It was found that a value of 6.8 k $\Omega$  for  $R_5$  gave the least harmonic distortion; this is of the same magnitude as suggested by Ridler<sup>1</sup> for similar transistors in his low-distortion oscillator design. This low value of  $R_5$  makes the output emitter follower rather a luxury but it does yield

an output resistance of under 30 $\Omega$  without feedback. The emitter load of 4.7 k $\Omega$  for  $Tr_4$  gives a reasonable battery consumption while still coping with quite high capacitance loading on negative-going signals.

With the feedback loop decoupled by an 80- $\mu$ F capacitor, a mid-band (1 kHz) open loop gain of 1,500 to 2,000 was typically obtained. A greater degree of feedback decoupling can be achieved with a given capacitor if it is put at the centre tap of  $R_2$ , rather than across  $R_1$ . The gain was 3dB down at about 35 kHz.

When the non-inverting input in Fig. 2 was connected to common via a 1 k $\Omega$  resistor (to equal that at the inverting input) the standing output voltage was typically a few tens of millivolts. Increasing this 1 k $\Omega$  resistor to 100 k $\Omega$  gave an output of some -1.6 V; i.e.  $1.6 \times 1/25$  V across 100 k $\Omega$ , indicating an input current of about 0.6  $\mu$ A. With the feedback decoupled, it was found that a 100 k $\Omega$  resistor in series with the a.c. input reduced the output by 50%, yielding a differential input resistance of 100 k $\Omega$ . Similarly,  $Tr_2$  will only lightly load the feedback network. With the a.c. restored as in Fig. 2 to give a gain of 25, the input resistance became about 2.5 M $\Omega$ , increasing to some 6 M $\Omega$  as the gain was reduced to 10.

With the feedback increased to reduce the closed loop gain much below 10, the prototypes tended to oscillate at some 5 to 10 MHz, depending on layout, etc. For stable operation with unity gain, the open loop turnover frequency needed to be reduced from 35 kHz to 4 or 5 kHz. This was achieved by putting 0.01  $\mu$ F and 100 $\Omega$  in series across the collector resistor of  $Tr_1$ , the 100 $\Omega$  preserving the risetime in the region of 0.25 to 0.5  $\mu$ sec. A feedback resistor of some 15 k $\Omega$  to 33 k $\Omega$  was used in the inverting or non-inverting mode and had to be shunted with 10 pF under these conditions.

With the configuration of Fig. 3 the a.c. input resistance was in the region of 200 M $\Omega$ . One must remember though that the source must still supply or pass the input bias current of 0.6  $\mu$ A. This would be a limitation, for instance, when trying to obtain long time constant displays in a peak reading circuit.

The output resistance was assessed by injecting a 1V r.m.s. signal via a 4.7 k $\Omega$

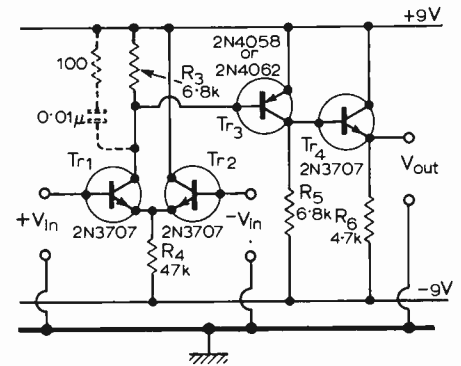


Fig. 1 The circuit of the simple operational amplifier

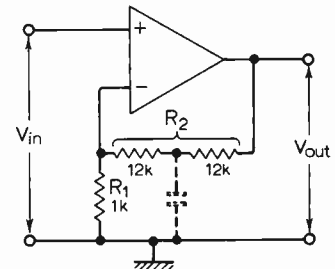


Fig. 2 The amplifier connected for the 'follower with gain' mode of operation. With the component values shown the gain is 25

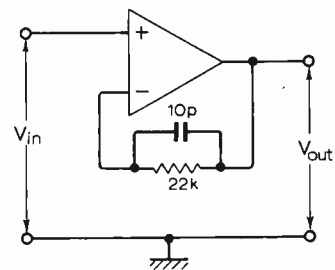


Fig. 3 Source follower with 100% feedback

resistor on to the output terminal and measuring the signal impressed on it. Without feedback, the voltage at A in Fig. 4 was 6 mV r.m.s., indicating that:

$$R_{out} = \frac{6 \times 10^{-3}}{1.0} \times 4.7 \text{ k}\Omega \approx 30\Omega.$$

At a gain of 25,  $R_{out}$  became about 0.6 $\Omega$ . This does *not* indicate that the circuit could drive a low impedance device such as a loudspeaker!

The amplifier distortion on sinewave drive was estimated with the aid of a passive twin-T null filter, making a rough correction for the attenuation of higher harmonics due to the broad response. Without a.c. feedback, 1 kHz at 1 V r.m.s. output gave a distortion of some 0.75%, rising to about 1.5% at 3 V r.m.s. output; about 4 V r.m.s. output can be expected before clipping starts. With this simple circuit one might expect the distortion to decrease in proportion to the degree of feedback applied. A check at a gain of 25 showed the output distortion to be indistinguishable from the degree of feedback applied. Excessive capacitance loading on the input will cause distortion which is particularly evident on negative-going signals when the output base-emitter junction tends to be cut off. With up to 0.01  $\mu$ F loading there was no increase in distortion at 15 kHz but 0.02  $\mu$ F produced a horrible amount of distortion components although the unfiltered output still looked very reasonable on a 'scope. Halving the value of the output resistor enables twice as much capacitive loading to be withstood at a given frequency.

The noise figure was measured by the elegant method recently described by Baxandall<sup>2</sup>, in which the temperature of the amplifier source resistor is varied in order to distinguish between amplifier noise and that introduced by thermal agitation in the source. Small metal oxide resistors were screened by pulling them up inside the braiding of good quality coaxial cable and their temperature was altered between that of liquid nitrogen (77°K) and room ambient. Fig. 5 shows the method of calculation.

At first sight one might expect to get a very poor noise factor with this circuit in the follower mode since the large thermal noise voltages in the high value 47 k $\Omega$  tail

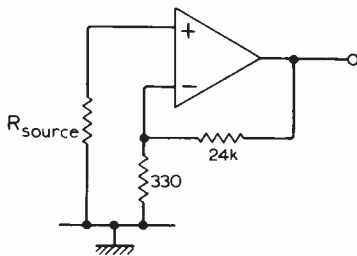


Fig. 6 Circuit used in noise function observations

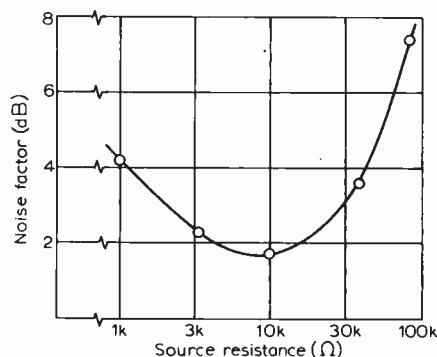


Fig. 7 Noise factor over band 100Hz to 20kHz as a function of source resistance

resistor are apparently in series with the input circuit. However, this viewpoint overlooks the effect of  $Tr_2$  which by its emitter follower action clamps the voltage at the top of the tail resistor at its base potential; thermal noise voltage fluctuations in  $R_4$  would be well suppressed. By the same token, though, the noise voltages in the resistance between  $Tr_2$  base and common will be coupled into the input in this mode of operation, together with a contribution from  $Tr_2$ . The 330 $\Omega$  resistor in Fig. 6 contributes a negligible amount to the amplifier noise factor which is shown in Fig. 7 for a bandwidth of 100 Hz to 20 kHz determined by RC time constants. Due to the logarithmic scale the dependence of noise factor on source resistance appears sharper than it is. The 2dB noise factor at the optimum source resistance of 10 k $\Omega$  is only increased by a further 2dB for inputs between 1 k $\Omega$  and 40 k $\Omega$ ; this would still be very satisfactory in most audio applications.

The amplifier can be used in the inverting or see-saw mode. This would probably not be needed too much in hi-fi work except for you know whose virtual earth tone control circuit<sup>3</sup>. For instruction in op. amp. applications, I would recommend references 4 and 5.

REFERENCES

1. P. F. Ridler: *Wireless World*, Aug. 1967.
2. P. J. Baxandall: *Wireless World*, Dec. 1968.
3. P. J. Baxandall: *Wireless World*, Oct. 1952 (See also "Cathode Ray", Nov. 1961.)
4. G. B. Clayton: *Wireless World*, Feb. to Dec. 1969.
5. "Application of Linear Microcircuits", SGS Ltd.

# Conferences and Exhibitions

Further details are obtainable from the addresses in parentheses

**LONDON**  
 July 13-17 Olympia  
**Ship's Gear International**  
 (Brintex Exhibitions, 3 Clements Inn, London W.C.2.)  
 July 22 & 23 Excelsior, London Airport  
**Marketing Electronic Products—Conference**  
 (*Electronic Business Review*, Morley Hse., Holborn Viaduct, London E.C.1)

**BANGOR**  
 July 6-10 University College  
**Microwave Spectroscopy**  
 (I.P.P.S., 47 Belgrave Sq., London S.W.1)

**LANCASTER**  
 July 20-24 The University  
**Dielectric Materials, Measurements and Applications**  
 (I.E.E., Savoy Pl., London W.C.2)

**LEEDS**  
 June 30-July 2 The University  
**Electronics Exhibition**  
 (C.S. Petch, Dept. of Elect. & Electronic Eng., University of Leeds, Woodhouse Lane, Leeds LS2 9JT)

**NEWCASTLE-UPON-TYNE**  
 July 7-9 The University  
**Scanning Electron Microscopy in Materials Science**  
 (I.P.P.S., 47 Belgrave Sq., London S.W.1)

**OVERSEAS**  
 July 14-16 Anaheim  
**Electromagnetic Compatibility**  
 (J.C. Senn, P.O. Box 1970, Anaheim, Cal. 92803)

July 16 Brussels  
**Conference Equipment Study Group: Simultaneous Interpretation**  
 (H. Fr. Schmidt, Technical Installations, Commission of the European Communities, Berlaymont Bldg, B-1040 Brussels.)

July 21-23 San Diego  
**Nuclear and Space Radiation Effects**  
 (I.E.E.E., 245 E. 47th St., New York, N.Y. 10017)

## Solution to this month's Crossword (see p. 336)

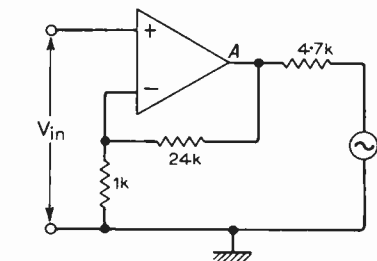


Fig. 4 Circuit employed to assess output resistance

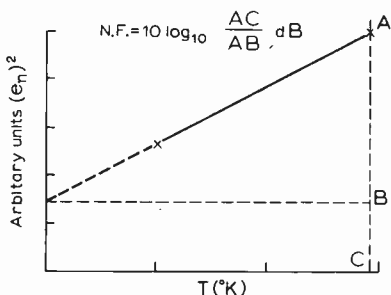


Fig. 5 Square of amplifier noise ( $e_n$ ) output as a function of the temperature of the source resistance



# Noise in Transistors

## A short explanation of noise performance of bipolar and field effect transistors at frequencies of a few kHz to a few MHz

by F. N. H. Robinson,\* M.A., D.Phil.

At low frequencies, below a few kHz, the chief source of transistor noise is flicker, or  $1/f$  noise, and no simple, generally valid, theory exists. Above a few hundred MHz the noise behaviour, like the signal behaviour, becomes quite complicated and cannot profitably be discussed in simple terms. In the intervening region, i.e. about 5 decades in frequency, noise in both bipolar and field effect transistors is remarkably simple.

In bipolar transistors the current injected into the base by the emitter consists of electrons which had enough thermal energy to surmount the potential barrier at the depletion layer. It is therefore completely random and displays full shot noise. In a bandwidth  $df$  the mean square fluctuations in the emitter current  $I_e$  are given by

$$di_e^2 = 2eI_e df \quad (1)$$

where  $e$  is the electronic charge. In the base, some electrons recombine and constitute the base current, the remainder reach the collector. This random division, of a random current, leads to two uncorrelated sets of fluctuations in the base current  $I_b$  and the collector current  $I_c$ . Their magnitudes are

$$di_b^2 = 2eI_b df \quad (2)$$

$$\text{and } di_c^2 = 2eI_c df \quad (3)$$

and, because they are uncorrelated,  $d(i_b i_c) = 0$ .

Because any equivalent circuit for a transistor must lead to the relation  $i_e = i_b + i_c$ , we do not need to consider  $i_e$  separately. Thus the noise properties are completely specified by  $i_b$  and  $i_c$ . A complete noise equivalent circuit for the transistor is shown in Fig. 1.

\*Clarendon Laboratory, University of Oxford.

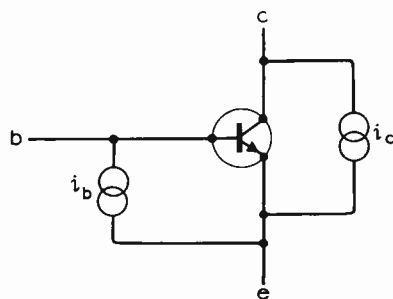


Fig. 1. Noise equivalent circuit for a bipolar transistor, valid up to 200 MHz.

The strengths of the two current generators are given by (2) and (3) and they are uncorrelated. This circuit is valid up to frequencies approaching  $f_T/\beta^2$ . If  $f_T = 2$  GHz and  $\beta = 100$  this can be as high as 200 MHz.

If the transistor is used in the common emitter connection it will have a mutual conductance

$$g_m = \frac{eI_c}{kT} \quad (4)$$

and we can transfer the current generator  $i_c$  to the input as a voltage generator  $v = i_c/g_m$ . Its strength is therefore

$$dv^2 = \frac{2kT}{g_m} df \quad (5)$$

In Fig. 2 is shown an equivalent circuit for a common-emitter stage connected to a signal source of internal impedance  $R_s$ . The

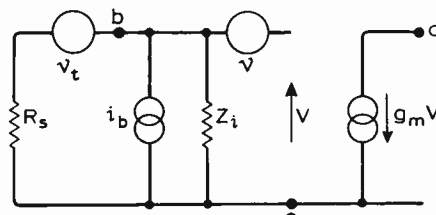


Fig. 2. An equivalent circuit for a common-emitter stage.

circuit includes the two noise generators  $i_b$  and  $v$  and the thermal noise generator  $v_t$  associated with the source at a temperature  $T_s$

$$dv_t^2 = 4kT_s R_s df \quad (6)$$

If we assume that the input impedance  $Z_i$  of the transistor is large compared with the source impedance  $R_s$  the total noise input is given by

$$dV^2 = 4kT_s R_s df + \frac{2kT df}{g_m} + 2eI_b R_s^2 df \quad (7)$$

The noise figure  $F$  is the ratio of this total noise to the noise due to the source alone (the first term in (7)), so that

$$F = 1 + \frac{T}{2T_s} \left( \frac{1}{g_m R_s} + \frac{eI_b R_s}{kT} \right)$$

We can also write this as

$$F = 1 + \frac{T}{2T_s} \left( \frac{1}{g_m R_s} + \frac{I_b}{I_c} g_m R_s \right) \quad (8)$$

The optimum source resistance is

$$R_s = \frac{1}{g_m} \sqrt{\frac{I_c}{I_b}} = \sqrt{\frac{dv^2}{di_b^2}} \quad (9)$$

Since the input impedance is approximately  $1/g_m I_c/I_b$  we see that our initial assumption that  $R_s \ll Z_i$  was justified. The optimum noise figure is now

$$F = 1 + \frac{T}{T_s} \sqrt{\frac{I_b}{I_c}} \quad (10)$$

If for example  $T = T_s$  and the d.c. current gain is 100 we have  $F = 1.1$  or about  $\frac{1}{2}$  dB. If the collector current is 1 mA we have  $1/g_m = 25 \Omega$  and  $R_s = 250 \Omega$  compared with  $Z_i = 2,500 \Omega$ .

Notice first of all that a good low-noise transistor must have a high d.c. current gain and secondly that  $R_s$  is quite low. Fortunately an error of a factor 2 in  $R_s$  only increases  $F$  to 1.125 so that there is no point in attempting to be too precise in designing input stages.

If  $R_s$  is fixed then  $I_c$  (and thus  $g_m$ ) should be adjusted to satisfy (9). If  $R_s$  is high e.g.  $50 \text{ k}\Omega$  and the d.c. current gain is 400 it is easy to see that the optimum  $I_c$  is  $10 \mu\text{A}$ . For this reason low-noise transistors should also have high current gain at low currents. This is not usually compatible with good r.f. response. Provided that the input capacitance of the transistor is tuned out, the formula for the optimum value of  $R_s$  is valid up to about  $\frac{1}{3} f_T$  but the noise figure begins to deteriorate appreciably at about  $f_T/\beta^2$ . At very high frequencies, the effect of base series resistance becomes appreciable and, in any case,  $F$  exceeds  $1 + f/f_T + (f/f_T)^2$ .

In f.e.t.s noise arises from thermal noise in the channel. When allowance has been made for the distributed nature of the noise source, the effect is equivalent to a current generator whose strength is

$$di_d^2 = \frac{2}{3} 4kTg_m df$$

connected between drain and source. This is equivalent to a voltage generator of strength

$$dv^2 = \frac{2}{3} \frac{4kT}{g_m} df \quad (11)$$

in the gate lead.

At low frequencies there is also current noise in the gate lead due to leakage  $I_g$

$$di_g^2 = 2eI_g df \quad (12)$$

but at high frequencies this is swamped by induced current noise, produced by fluctuations in the channel under the gate. This noise is to all intents uncorrelated with the drain noise and is of magnitude

$$di^2 = \frac{1}{4} \frac{\omega^2 C^2}{g_m} 4kT df \quad (13)$$

where  $C$  is the input capacitance. The complete equivalent circuit is shown in Fig. 3.

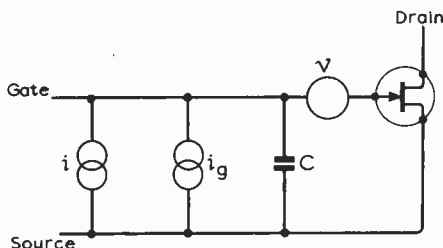


Fig. 3. An equivalent circuit for a field effect transistor.

The optimum source resistance and noise figure at low frequencies are

$$R_s = \left( \frac{dv^2}{di_g^2} \right)^{\frac{1}{2}} = \left( \frac{4kT}{3eI_g g_m} \right)^{\frac{1}{2}} \quad (14)$$

and

$$F = 1 + \left( \frac{8eI_g}{3kTg_m} \right)^{\frac{1}{2}} \quad (15)$$

If  $I_g = 10^{-9}$  A and  $g_m = 5$  millimho, we have  $R_s \approx 100$  k $\Omega$  and  $F \approx 1.005$ .

At high frequencies the optimum values are

$$R_s = \frac{1}{\omega C} \sqrt{\frac{8}{3}} \quad (16)$$

and

$$F_o = 1 + \frac{\omega C}{g_m} \sqrt{\frac{2}{3}} \approx 1 + \frac{f}{f_T} \quad (17)$$

where  $f_T = g_m/2\pi C$  is the gain bandwidth product. Obviously good low-noise r.f. amplifiers require f.e.t.s with a high gain bandwidth product.

Insulated gate f.e.t.s tend to have high flicker noise and these results are only valid above about 1 MHz., but, for junction f.e.t.s, they are often valid down to low audio frequencies.

Perhaps the most important part to bear in mind is that there is an optimum source impedance, and that for bipolar transistors this is much less than the input impedance. If the source impedance is high, an f.e.t. will usually be the most suitable input stage. Conversely for low source impedances it will be a bipolar transistor. Finally it should be noted that the use of negative feedback, or other connections (e.g. common base) alters neither the optimum source impedance nor the optimum noise figure.

#### REFERENCE

1. "Equivalent Circuit for Noise in Bipolar Transistors", by H. Sutcliffe, *International Journal of Electrical Engineering Education*, vol. 6, number 3, October 1968.

## Domestic video records

Machines for playing recorded vision programmes into domestic television sets are arriving from all directions. Some are players only, for reproducing programme material on records supplied by outside organizations. Others will, in addition, record and reproduce television programmes (broadcast or closed-circuit) selected by the user. The two latest are the Video Cassette Recorder, from Philips (Holland), shown below, and the Cartrivision system, from Avco (U.S.A.).

The Philips machine (called VCR, perhaps for its convenient euphonic relationship with EVR) was demonstrated in the U.K. at a convention of the Film Industry Organization at Brighton. As the name indicates the machine uses cassettes to hold the recording medium, which is  $\frac{1}{2}$ -inch magnetic tape. The recorded material, colour or monochrome, is reproduced on a domestic television receiver, and connection to the set is made via the aerial socket.

Two versions of the machine have been produced. The first is a player only, intended for reproducing programme material supplied in cassettes by outside organizations—hence the interest of the film industry. This is expected to cost about £120 for a monochrome machine and about £140 for a colour machine. The second

version, justifying the name, will record as well as reproduce, and for recording broadcast television programmes it obtains the video signal by means of a built-in tuner which receives its r.f. signal from the aerial connection on the home television set. This machine will cost about £230.

Each cassette contains enough tape for an hour's running. It can be put into or taken out of the machine very easily and at any required moment, regardless of the position of the tape. Programme material may be erased and fresh material recorded in its place, as with a sound tape recorder. No rewinding is required.

The cassettes are interchangeable in the sense that, provided they are of the right type to fit the VCR, they can come from any source. Also, colour and monochrome cassettes are compatible, in that either type can be played on monochrome machines and colour machines. On the  $\frac{1}{2}$ -inch tape two sound record tracks are available, and these can be used, say, for stereophonic sound or for spoken commentaries in two languages.

Other domestic video reproducing systems already launched or announced have the trade names: EVR (Electronic Video Recording), Vidicord, Selectavision and Sony. Domestic v.t.r. machines are already on the market.



# Active Filters

## 12. The Leapfrog or Active-Ladder Synthesis

by F. E. J. Girling\* and E. F. Good\*

Certain types of passive filter have low sensitivity to errors in component values. Of these the best known types have the form of a ladder, terminated in equal resistances, but otherwise LC and lossfree. The leapfrog or active ladder synthesis allows a close analogue of such a filter to be made, in which integrators replace the reactances with a one-to-one correspondence, and which has the same low sensitivity (provided certain pairs of resistances keep a sensibly constant ratio). The synthesis is, therefore, especially useful for filters which must be designed to a tight specification.

The synthesis may be regarded as an extension of the use of the two-integrator loop.

### Sensitivity

Active filters may be divided into three classes: those with high sensitivity to errors, i.e. those in which errors are exaggerated, so that an error of  $x\%$  in some critical component causes an error much greater than  $x\%$  in some important performance parameter; those with medium sensitivity, i.e. those in which errors in component values cause no more than proportional changes in important performance parameters; and those with low sensitivity, i.e. those which, at least in the pass band, are relatively insensitive to changes in component values. In any filter, whether active or passive, a change in the value of any component whose value enters into one of the time constants or LC products of the transfer function must cause a movement of the response curve along the frequency scale. The sort of change we are discussing is a change in the shape of the response curve such as a broadening or narrowing of the passband, or an increase in unevenness.

In all CR active filters positive feedback (in the strictest sense of the term) must operate to raise the Q factors of CR networks from  $\leq \frac{1}{2}$  to higher values, and in high-performance filters to much higher values. This means that there are feedback loops for which the input quantity is the vector difference of two larger and nearly equal quantities. In circuits of high sensitivity there is no significant constraint on the relative magnitudes or on the phase difference of the two larger quantities, a not very large change in the value of a critical component can cause the difference to be-

come zero, and a small change can cause a proportionately much larger change in the magnitude of the difference. This causes a change in gain over a narrow band of frequencies with the undesirable effects already mentioned. In circuits of medium sensitivity the difference between the two large vectors can become zero (if it can happen at all) only as a limiting case, when the ratio of some pair of components becomes infinite, and small changes in the value of a component cause no more than proportional changes in the magnitude of the difference. Circuits of this class were described in Parts 5, 6, and 7.

In a filter of low sensitivity there are constraints on the performance which result in errors in component values having a less than proportional effect on the more important characteristics of the response. Thus in a passive filter of this class, in the pass band the (ideally loss-free) LC network gives almost optimum power match between load resistance and source resistance and the response is close to the maximum possible. Clearly no error, however great, can raise the response above the maximum possible, and the effect of small errors is minimal. If an active filter is to have a similar low sensitivity it must be subject to similar constraints, and this will be the case if it is an analogue of the passive filter to the extent of copying its internal working, so that an error in a critical component has the same effect as an equal percentage error in the counterpart in the passive filter.

### Copying

Active 2nd-order systems such as the integrator-and-lag and the two-lag loop with negative gain discussed in Parts 5 and 6 copy the working of a 2nd-order passive LCR network sufficiently closely to have the same sensitivity to component tolerances. And the same is true of the two-integrator loop, Part 7. An explanation is that the coefficients of the denominators of the transfer functions are built up from products and ratios with the dimensions of time such as CR, L/R, in virtually the same way. Thus the transfer functions of both the low-pass systems of Fig. 1 may be written (if in one case the prefixed minus sign is omitted)

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 + T_1 p + T_1 T_2 p^2} \quad (1)$$

where for the passive circuit  $T_1 = CR$  and  $T_2 = L/R$ , and for the active system  $T_1 = C_1 R_1$  and  $T_2 = C_2 R_2$ .

When several sections are cascaded to form a higher-order filter as described in Part 9, the system obtained is equivalent to a cascade of 2nd-order LCR networks separated by buffer amplifiers, and is virtually Butterworth's filter-amplifier approach (Ref. 1). The sensitivity to component tolerances is clearly the same as that of the individual 2nd-order stages, and it is not the same as for a well designed equally terminated LCR filter. In this type of filter, in the pass band, where the LC network approximates to an ideal transformer matching the load resistance to the source resistance and the loss is close to the minimum possible (6dB), the effect of changes in the value of a component is as shown in curve A, Fig. 2 (see Orchard, Ref. 2), whereas for the factor method a curve such as B applies.

Thus for the 1-p filter with Chebyshev response shown in Fig. 3(a) a 30% reduction in  $C_3$  gives only the small change in response shown by curve (2) of Fig. 3(c), whereas an equal reduction in the time constant of the first stage of the synthesis by factors shown in Fig. 3(b) causes a much greater change in response, curve (3) of Fig. 3(c). In the equally-terminated filter the response is constrained to remain of equal-ripple type

$$\frac{V_{out}}{V_{in}} = \frac{k}{(1 + qpT)(1 + pT/q + p^2 T^2)} \quad (2)$$

and the reduction in  $C_3$  causes not only a reduction in the time constant of the 1st-order factor but also reduction in the  $q$  of the 2nd-order factor, which has a compensating effect. In the synthesis by factors the reduction in  $C_3$  makes no change in the 2nd-order factor. In the cut-off region, however, there is no significant difference between the two methods. Here the response is dominated by the coefficient of  $p^3$

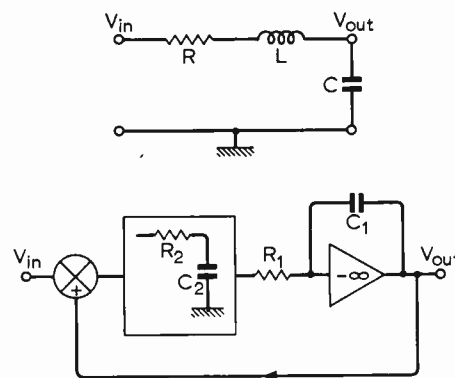


Fig. 1. A lag-and-integrator loop copies a passive 2nd-order network to the extent of having the same sensitivity to errors in component values.

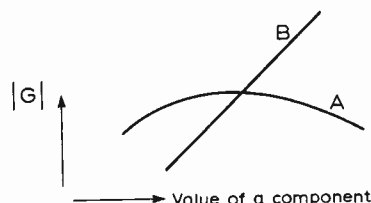


Fig. 2. Two types of sensitivity.

\*Royal Radar Establishment.

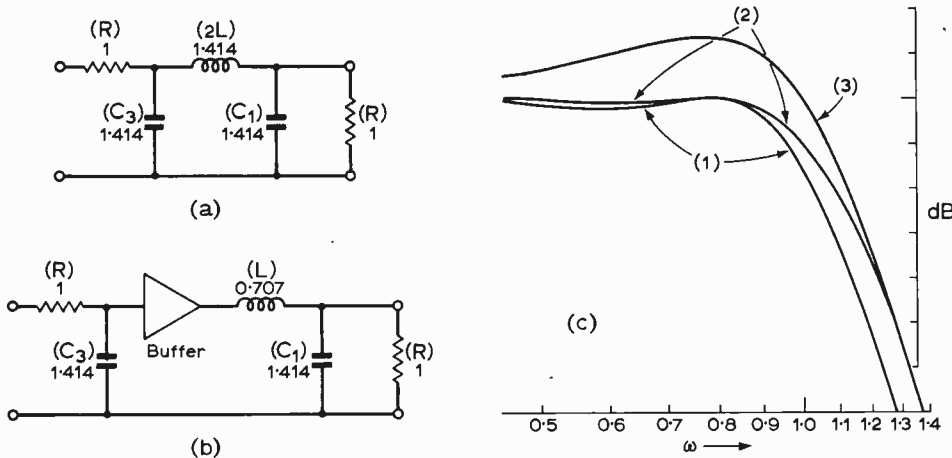


Fig. 3. Two filters which give the same response when component values are accurate, but have different sensitivity.

in the expansion of the denominators of the transfer functions:

$$F(p) = \frac{k}{D(p)} = \frac{k}{1 + ap + bp^2 + cp^3} \quad (3)$$

For each  $c = C_1LC_3R$  and the response at high frequencies (relative to the response at zero frequency) approximates to

$$|G(\omega)| = 1/C_1LC_3R\omega^3 \quad (4)$$

Of course an error of 30% is unrealistically large, and in practice for such a simple filter synthesis by factors would probably be quite satisfactory. The example does illustrate, however, how the equally terminated structure gives in the passband reduced sensitivity to an error in the value of one of the reactances.

In a narrow band-pass filter, where component tolerances must in any case be tight if the specified centre frequency and band limits are to be obtained, the higher sensitivity of a synthesis by factors, calling for even tighter tolerances (or very close matching of components), could be a serious embarrassment, and the lower sensitivity of an equally terminated structure would be of

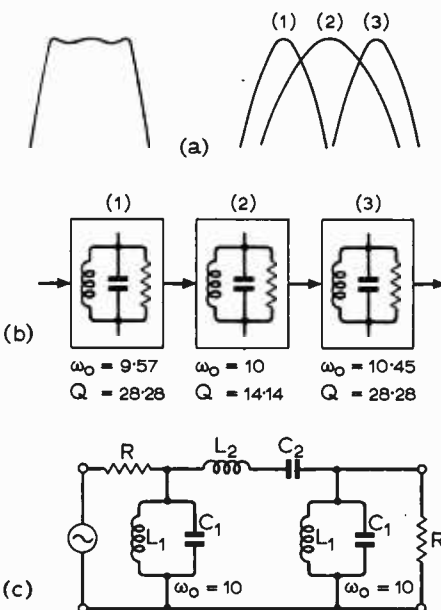


Fig. 4. Realisation of a band-pass characteristic (a): by factors (b); by an equally terminated structure (c).

real advantage. Fig. 4 shows schematically a band-pass filter of relative bandwidth 1/10 synthesised by factors and as an equally terminated structure. The factor synthesis is the method of stagger tuning, and Fig. 5(a) shows the effect of mistuning the low-Q factor by 1% (by a 2% error in the respective tuning capacitance). A pronounced tilt appears in the passband, and mistuning of either of the outer factors also causes a considerable change in mean level. In Fig. 5(b)

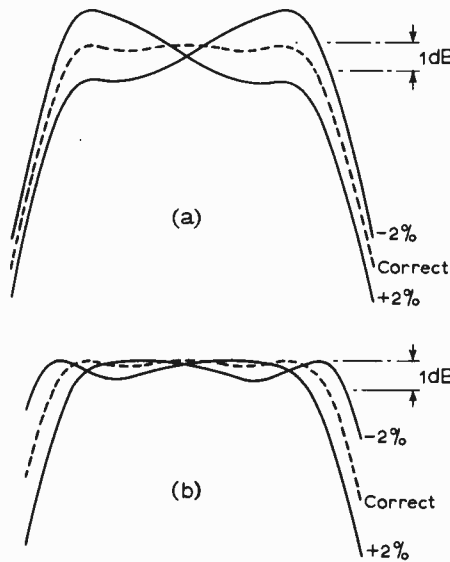


Fig. 5. Sensitivity of the two filters of Fig. 4: (a) synthesis by factors,  $C_2 \pm 2\%$ , (b) equally terminated filter,  $C_2 \pm 2\%$ .

are shown the effects of 2% errors in one of the capacitances in the equally terminated structure, and it can be seen that the increase in ripple or unevenness is approximately only 1/3rd as much as shown in Fig. 5(a). So if a  $\pm 1\%$  tolerance were needed in the equally terminated structure, a  $\pm 0.2\%$  tolerance would have to be set for the synthesis by factors (at least for the ratios of the Cs and for the ratio of the Ls).

In the equally terminated structure an error in a component causes reactions throughout the structure, and as the examples show these are to a considerable extent compensatory. If an active structure is to reproduce this behaviour it must be an

analogue to the extent of duplicating these internal reactions, and not merely by a system which, when all values are accurate, gives the same transfer function.

Now it has already been shown in Part 7 that a two-integrator loop is an analogue of an LCR tuned circuit, one integrator taking the place of the inductance and the other of the capacitance. Resonance in the LCR circuit arises from the oscillatory interchange of energy between the magnetic field of the coil and the electric field of the capacitor. In the two-integrator loop gain and feedback allow us to use two energy stores of the same kind and so obtain resonance with only one kind of reactance (normally capacitance). The question arises, therefore, can a system of integrators and feedback links be set up to reproduce the performance of more complicated LCR networks—perhaps any LCR network—and in particular a ladder structure in which all the elements except the terminating source and load resistances are lossless reactances?

**All-integrator circuits**

For a long time it has been obvious to anyone with a knowledge of analogue computing that if the chosen passive model or response curve is reduced to a transfer function, this can be "instrumented" by standard methods and an active filter obtained consisting of integrators and inverting stages. But in the resultant structure it is not possible to identify one of the integrators with one of the reactances of the passive prototype. About all that can be done of that sort is to identify certain resistors as corresponding to the coefficients of the terms of the denominator and numerator of the transfer function. A theoretical schematic for 3rd-order transfer functions is given in Fig. 6. So the method no more produces a filter with the looked-for one-to-one correspondence than a synthesis by factors; and since it can be shown that a finite change in the value of a component can make such a system unstable (oscillate), i.e. cause an infinite change in response, it seems likely that the sensitivity to errors will be greater.

**The leapfrog synthesis**

Fig. 7(a) shows a 2nd-order l-p filter, or, equally well, the output end of some longer

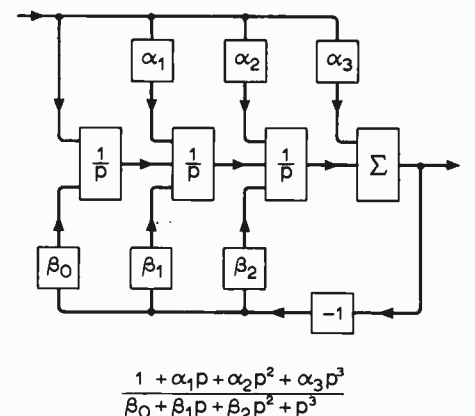


Fig. 6. "Analogue-computer" realisation of a 3rd-order transfer function.

l-p ladder. By dividing all impedances by  $R$  in Fig. 7(b) the network has been normalised to make the terminating resistance 1 ohm. This simplifies the synthesis, though it makes some of the equations in the analysis appear dimensionally incorrect.

As usual with a ladder, the network is conveniently analysed by supposing an output voltage and finding the currents and voltages that must exist to produce it:

$$I_0 = V_{out}/(1 \text{ ohm}) \quad (5)$$

$$I_1 = pCRV_{out} \quad (6)$$

$$I_2 = I_0 + I_1 \quad (7)$$

$$V_L = (pL/R)I_2 \quad (8)$$

$$V_{in} = V_{out} + V_L \quad (9)$$

whence

$$V_{in} = (1 + pL/R + p^2LC)V_{out} \quad (10)$$

An active system, using abstract integrators, which is described by an exactly parallel set of equations, is shown in Fig. 7(c). The dependent variables at the inputs and outputs of the integrators and differential gears are designated by  $\theta$ s to indicate the generality of the analogue, for in principle they can be any physical quantity capable of oscillatory motion (e.g. the angular position of a shaft). When electronic integrators are used, however, they will be electrical quantities, and when the ubiquitous Blumlein (or Miller) feedback integrator is used, voltages. Thus voltages will represent both the voltages in the passive circuit, and the currents; and any feeling of dimensional inconsistency which this may give can be removed by supposing the currents multiplied by an arbitrary resistance. In the schematic of Fig. 7(b) this resistance is the 1 ohm termination of the passive network, but in a practical situation some other value may be advisable. If, for example, the system is lightly damped, near the upper end of the passband  $I_1$  will be considerably greater than  $I_0$ . But  $\theta_1$  and  $\theta_{out}$  can have equal amplitudes if a suitable scaling factor  $k$  is introduced into the paths

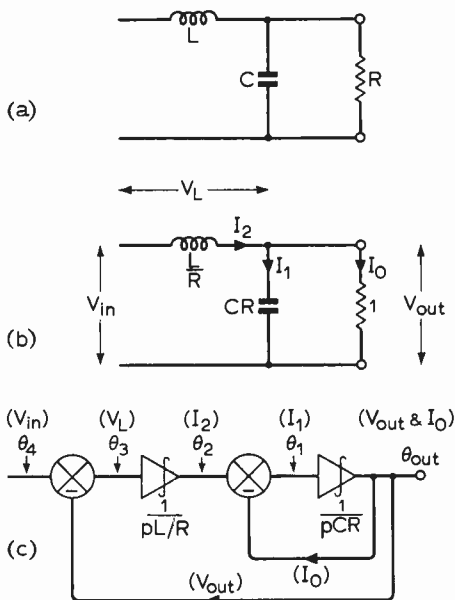


Fig. 7. The two reactances at the output end of a low-pass ladder are replaced by two integrators.

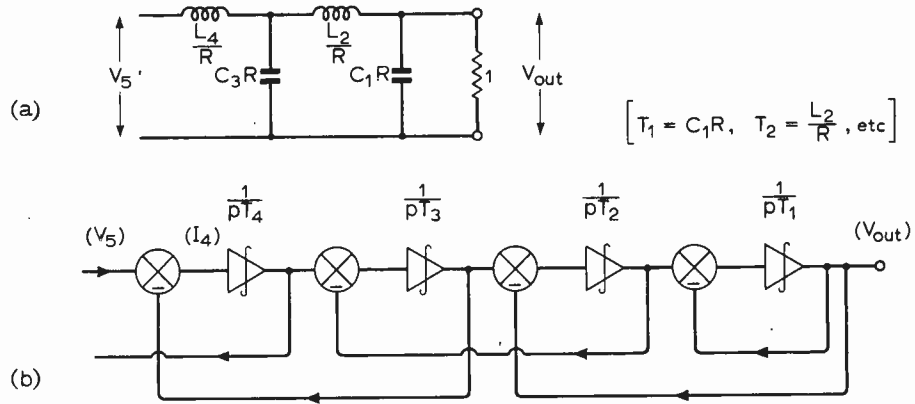


Fig. 8. The ladder is lengthened.

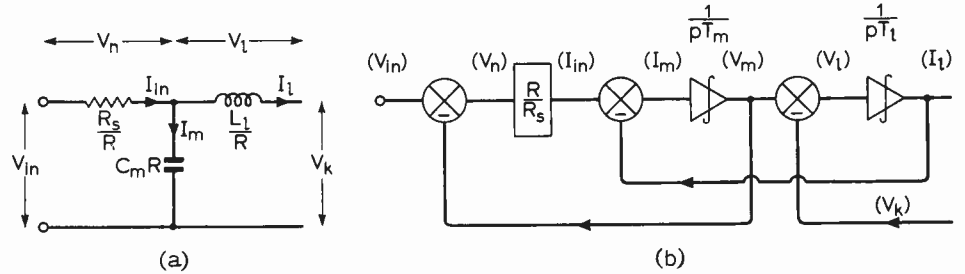


Fig. 9. The effect of the terminating resistance at the sending end is reproduced.

leading both to and away from  $\theta_1$ , i.e. if the  $T$ s of the integrators are made  $kL/R$  and  $CR/k$ , and the feedback representing  $I_0$  is reduced to  $1/k$ . Indeed in principle different scaling constants may be used at each point, since the only rule to be observed to leave the dynamic properties of the system unchanged apart from a scalar multiplier is that for every feedback loop the loop gain (the product of the gains of the forward and feedback parts of the loop) must be unchanged. This flexibility has already been noticed in Part 7, where the two-integrator loop is derived as an analogue of a series LCR circuit, and is helpful in allowing best use to be made of the internal gain and the dynamic range of the integrator amplifiers.

Equations (5) to (9) are of three types: simple summations representing Kirchhoff's laws for the currents at a node or the voltages round a mesh; 1st-order differential equations representing the action of the reactances; and the Ohm's-law equation describing the proportionality of current and voltage for a resistance. When the ladder is extended, Fig. 8(a), no new types of process are brought into action, only the same types of equation are needed in the analysis, and the active analogue can be correspondingly lengthened by adding further integrators and feedback connections as shown in Fig. 8(b). The lengthening of the passive ladder and of the corresponding active system may be continued without limit, the number of integrators in the latter always equalling the number of reactances in the former, and at the input end it is easy to add a final feedback loop to duplicate the action of the source resistance,  $R_s$  (Fig. 9). Thus an active synthesis has been found which gives a one-to-one correspondence between the reactances of the passive filter and the integrators of the active system and duplicates not only the overall response of a simple low-pass ladder of any length, but also, as required, the internal workings.

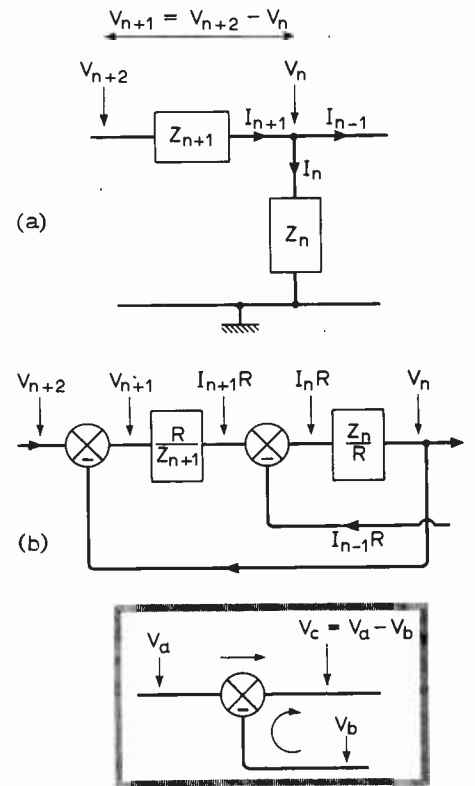


Fig. 10. Formal derivation of the active ladder.

**Theorem**

A simple ladder working with voltage input and voltage output can be divided into inverted-L sections, and a more formal derivation of the synthesis may be made by first proving the following theorem.

The inverted-L section of a ladder network as shown in Fig. 10(a) gives when passing signals from left to right the same

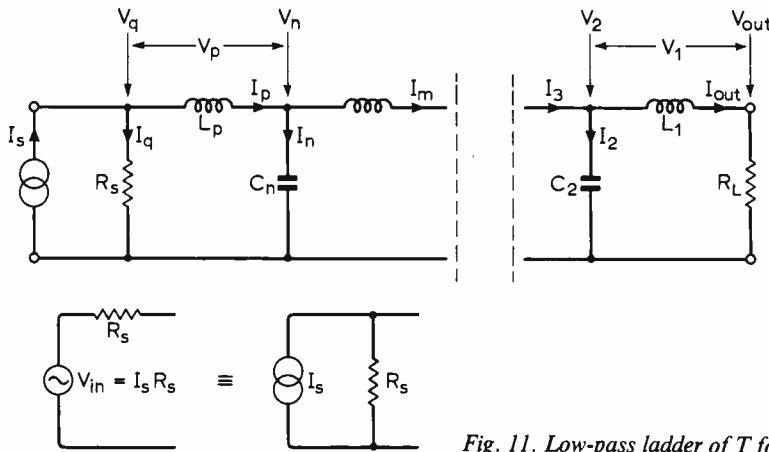


Fig. 11. Low-pass ladder of T form.

transmission as the active analogue shown in Fig. 10(b).

In the passive network

$$\begin{aligned}
 I_n &= V_n/Z_n \\
 I_{n+1} &= I_n + I_{n-1} \\
 &= V_n/Z_n + I_{n-1} \\
 V_{n+1} &= I_{n+1}Z_{n+1} \\
 &= (V_n/Z_n + I_{n-1})Z_{n+1} \\
 V_{n+2} &= V_n + V_{n+1} \\
 &= V_n(1 + Z_{n+1}/Z_n) + I_{n-1}Z_{n+1}
 \end{aligned}$$

In the active system there are two amplifiers of gain  $Z_n/R$  and  $R/Z_{n+1}$  respectively and two difference boxes which take the difference of the voltage applied from the left and the feedback voltage, so that  $V_a = V_b - V_c$  as shown inset. If then a voltage  $= I_{n-1}R$  is available from another section, it can be seen by inspection that

$$\begin{aligned}
 I_n R &= V_n R/Z_n \\
 I_{n+1} R &= I_n R + I_{n-1} R \\
 &= V_n R/Z_n + I_{n-1} R \\
 V_{n+1} &= I_{n+1} Z_{n+1} \\
 &= V_n Z_{n+1}/Z_n + I_{n-1} Z_{n+1} \\
 V_{n+2} &= V_n(1 + Z_{n+1}/Z_n) + I_{n-1} Z_{n+1}
 \end{aligned}$$

q.e.d. [ $R$  is an arbitrary resistance.]

When the shunt impedance  $Z_n$  is  $1/pC_n$  the reactance of an ideal capacitor, the gain  $Z_n/R = 1/pC_n R$ , which is the voltage transfer ratio of an integrator. And when the series impedance  $Z_{n+1}$  is  $pL_{n+1}$  an ideal inductive reactance, the gain  $R/Z_{n+1} = 1/(pL_{n+1}/R)$ , which also is the transfer ratio of an integrator. Thus the synthesis allows inductance to be simulated by capacitance, which is the object of the exercise.

For the output section of the ladder a terminating load resistance makes  $I_{n-1} = V_{out}/R_L$ . Hence in the active system the required feedback is a voltage proportional to  $V_{out}$ . Alternatively the load resistance may be taken as in parallel combination with the shunt impedance  $Z_n$  and the final amplifier of the active system assigned a gain  $Z_n R_L / (Z_n + R_L) R$ . If  $Z_n = 1/pC$  this reduces to  $R_L / R(1 + pCR_L)$ . So the amplifier should have the response of a simple lag of time constant  $CR_L$  combined with a zero-frequency gain  $R_L/R$ . If the amplifier has the form of an integrator a resistance is

placed across the integrating capacitor. For all other sections the voltage  $I_{n-1}R$  is available from the section to the right.

At the input end a source resistance  $R_s$  calls for a voltage  $I_{n+1}R_s$  to be introduced in series with the input, i.e. a voltage  $\propto I_{n+1}R$ , which is already present in the active system. Or again alternatively,  $R_s$  may be treated as combined with  $Z_{n+1}$  and the input amplifier given a gain  $R/(Z_{n+1} + R_s)$ . And again if  $Z_{n+1} = pL_{n+1}$  this has the form  $A/(1 + pT)$ .

**A ladder of T type**

If the reactances of the passive ladder are connected to form one or more tees, Fig. 11, the analysis of the action proceeds as follows:

$$\begin{aligned}
 V_{out} &= R_L I_{out} \\
 V_1 &= pL_1 I_{out} \\
 V_2 &= V_{out} + V_1 \\
 I_2 &= pC_2 V_2 \\
 I_3 &= I_{out} + I_2 \\
 &\dots\dots\dots \\
 V_n &= V_1 + V_m \\
 I_n &= pC_n V_n \\
 I_p &= I_m + I_n \\
 V_p &= pL_p I_p \\
 V_q &= V_n + V_p \\
 I_q &= V_q/R_s \\
 I_s &= I_p + I_q \\
 [V_{in} &= I_s R_s]
 \end{aligned}$$

If these are compared with the parallel set of equations for a  $\pi$ -form ladder, which begins as equations (5) to (9), it is found that

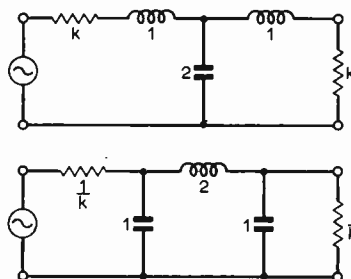


Fig. 12. T-form and  $\pi$ -form filters with the same response.

the sets are exactly the same except that the roles of voltage and current, and of inductance and capacitance are reversed. And it follows that the same active system, where one kind of quantity (voltage) represents both the voltages and the currents of the passive models, can represent both forms of ladder.

The correspondence between the two forms of ladder is, of course, well known, and explains why, for example, the two filters shown in Fig. 12 have the same voltage transfer ratio. Because of the exchange of roles between voltage and current, resistance in one form corresponds to conductance in the other; and whereas high values of  $R_s$  and  $R_L$  give light damping in the  $\pi$ -form filter, Fig. 12 (lower), low values give light damping in the T-form filter, Fig. 12 (upper).

**Drawing and naming**

The name "leapfrog feedback filter" was suggested by the appearance of the schematic diagrams when all the feedback links are drawn on one side of the row of integrators and difference boxes. If the feedback links are drawn alternately above and below the forward signal path crossings over are avoided, Fig. 13(b), and it is then easy to proceed to drawing the system as a ladder, as will appear in later diagrams.

**Electrical circuits**

Fig. 13(a) shows two 5th-order low-pass ladders, and Fig. 13(b) the block schematic of the active system which can equally well be the counterpart of either. This schematic is really a diagram of mathematical processes, and by using the precedent of the two-integrator loop it is easily appreciated that the difference boxes need not appear as separate entities and that each feedback loop will be closed in the correct sense if it contains two Blumlein ("Miller") integrators and one phase-inverting amplifier, as this gives, as required, an odd number of sign changes at zero frequency. The inverting amplifiers may be placed in positions  $\times_1$  giving Fig. 13(c), or in positions  $\times_2$  giving Fig. 13(d). The second is the more economical arrangement as it uses only two inverting amplifiers. The first has the possible advantage that there are fewer stages in the forward path—only the integrators.

In both Fig. 13(c) and in Fig. 13(d) there are considerably more than five resistances. If all have the correct value, then the five capacitances may be identified with the five reactances of the passive models, and the one-to-one correspondence principle is exactly observed. If in Fig. 13(d) one of the resistances marked  $r$  is in error, it is equivalent to an equal percentage error in the capacitance of the preceding integrator. So the active system still shows the desired correspondence with the passive models, though with an error in one of the reactances. And lack of infinite gain in the inverting amplifiers is also equivalent to a change in the  $T$  of the preceding integrator. An error in only one of a pair of resistances such as  $R_2, R_2'$ , however, has no exact counterpart in a change in the value of any single component in the passive models, since it

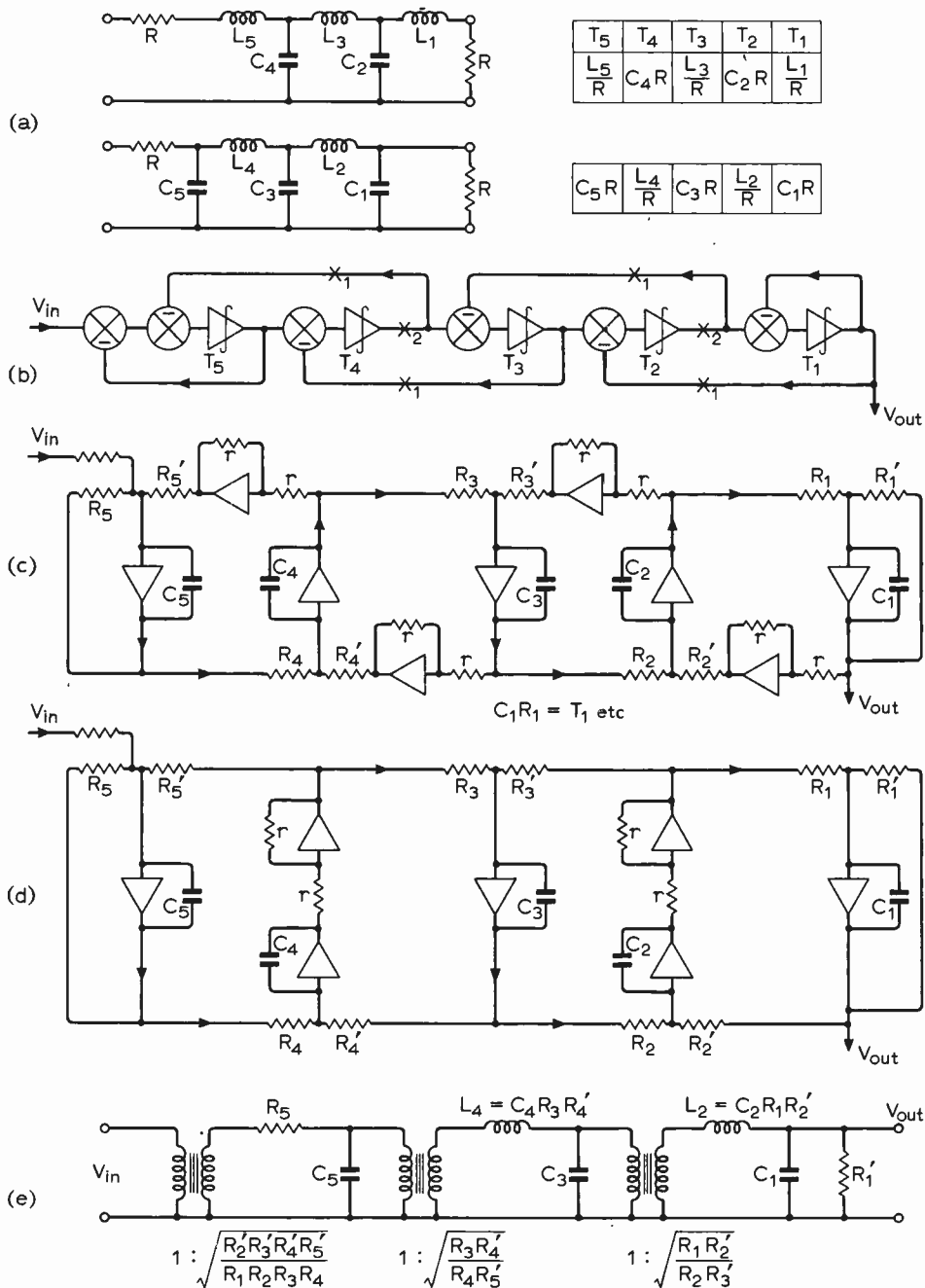


Fig. 13. Derivation of electrical active ladders.

causes one of the integrators to have a different *T* in one loop from another.

Suppose in Fig. 13(d) that *R*<sub>2</sub> is too small. The current in *R*<sub>2</sub> will be too large, all the signal levels to the right of *R*<sub>2</sub> will be increased, and in particular the feedback current in *R*<sub>3</sub>' (which represents the current in *L*<sub>2</sub> in the π-form model) is increased. The effect is the same as if an ideal transformer (effective down to zero frequency) of ratio 1:√(*R*<sub>2</sub>(nom)/*R*<sub>2</sub>) is interposed between *C*<sub>3</sub> and *L*<sub>2</sub> in the passive model. Similarly the effect of other possible errors in nominally equal resistors can be represented as shown in Fig. 13(e). Clearly, unless one of the terminating resistances *R*<sub>1</sub>' and *R*<sub>5</sub> is adjusted to compensate, the active system no longer exactly represents a power-matched structure. But with the errors to be expected from modern high-stability resistors, the departure from the ideal will be small and the effect will be no more serious than the effect of inequality in load and source re-

sistance in the passive model repeated a number of times.

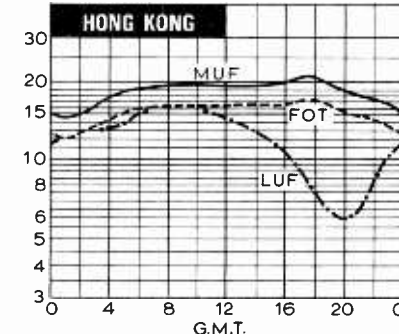
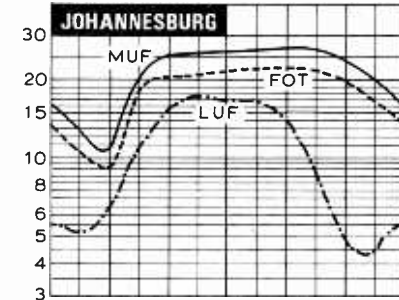
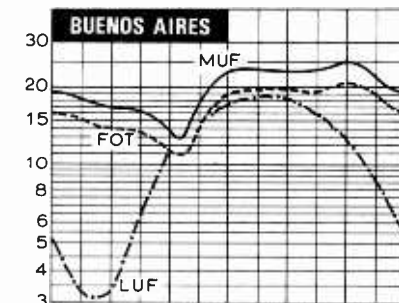
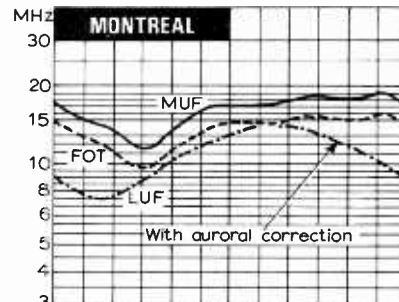
In Fig. 13(c) there are an even greater number of resistances to be in error; but by similar reasoning a passive model can again be constructed. That the active systems are analogues of passive models is itself an assurance that they cannot have high sensitivity to errors, since no finite change in component values can make the system unstable. The effects of any unwanted phase shifts are, of course, excluded in this argument.

**REFERENCES**

1. "On the Theory of Filter Amplifiers", by S. Butterworth. *Experimental Wireless and Wireless Engineer*, Oct. 1930, Vol. 7, No. 85, pp. 536-541.
2. "Inductorless Filters", by H. J. Orchard. *Electronics Letters*, June 1966, Vol. 2, No. 6, pp. 224-225.

# H.F. Predictions —July

The charts are based on an ionospheric index (IF2) of 94 and sunspot number 84. These values are predicted from smoothed data which include allowance observed during March/April. The Greenwich sunspot number for May was 136 showing that the high activity had, rather surprisingly, not only continued but further increased. If this activity is taken into account the median standard frequency (MUF) for Montreal would be 0.5MHz higher than that shown at 12.00 and 1.5MHz higher at midnight. The correction for the lowest usable frequency (LUF) would be in opposite sense—1MHz higher at 12.00 and unchanged at midnight. Other routes would be similarly affected. Disturbed days have been relatively frequent (April 15 days, May 6 days) and are expected to continue, but rarely intense.



# Coding Problems in Iterative Arrays

A logic circuit for multiplying by three is developed as an illustration

by K. S. Hall\*

In a recent article<sup>1</sup> K. J. Dean described how iterative arrays of logical circuits may be used to perform arithmetic operations, giving a number of examples. The purpose of the present article is to discuss some problems which arise in the design of these arrays, partly because the arrays themselves are interesting and useful, and partly because they form a convenient peg on which to hang a discussion of some problems that arise in the design of a wider class of logic circuits.

Dean begins by pointing out how networks for multiplication by two and four may be devised. These are shown in Fig. 1 which has been adapted from his article. As he says they are rather trivial, consisting merely of leads which transfer a digit to a more significant position. However they do serve as a convenient introduction to the next circuit, which is for multiplication by three. The form of the circuit is shown in Fig. 2. It should be pointed out that while there is one input wire *A* and one output wire *B* for each block, the number of wires between blocks bearing information about the carry digit *C* is as yet undetermined. The problem is to design the circuit within each block.

### Design of a component block

The function of each block is to add together two numbers. One, which we will call *a<sub>r</sub>*, has the value 0 when *A<sub>r</sub>* = 0 and the value 3 when *A<sub>r</sub>* = 1. The other, *c<sub>r</sub>*, is carried from the block on the right. The greatest value that *c<sub>r</sub>* can have is given by:

$$2^r c_r \leq 3(2^r - 1)$$

so that *c<sub>r</sub>* is 0, 1 or 2. To distinguish these three values requires two binary digits and the coding problem is to decide how best to use the four possible combinations of these digits to convey three alternative messages about the value of the carry digit.

Dean proposed to give the two digits weights of 1 and 2 respectively, so that 00, 01 and 10 represent carry digits of 0, 1 and 2 respectively, and 11 was not used at all. One block of the array may now be redrawn as in Fig. 3, showing the two binary digits separately, and the table of combinations, giving the values of *B<sub>r</sub>*, *P<sub>r+1</sub>* and *Q<sub>r+1</sub>* in terms of *A<sub>r</sub>*, *P<sub>r</sub>* and *Q<sub>r</sub>*, may be drawn up as shown in table one.

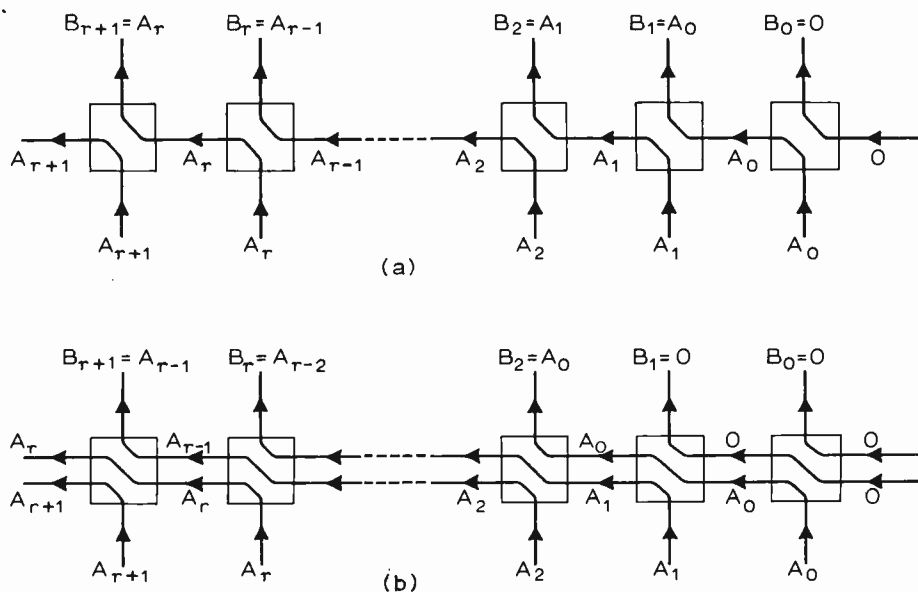


Fig. 1(a). An array for multiplication by two. (b) an array for multiplication by four. In both cases leads merely transfer digits to a more significant position.

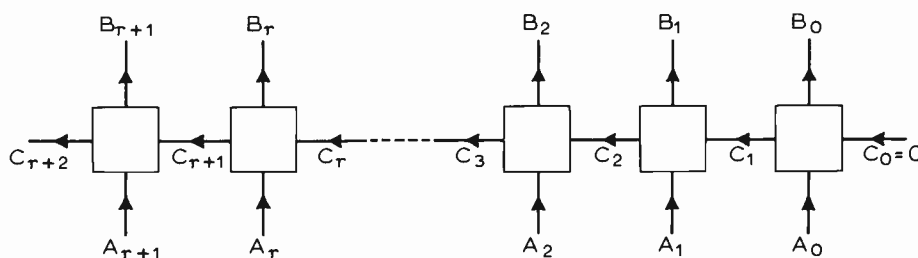


Fig. 2. An array for multiplication by three.

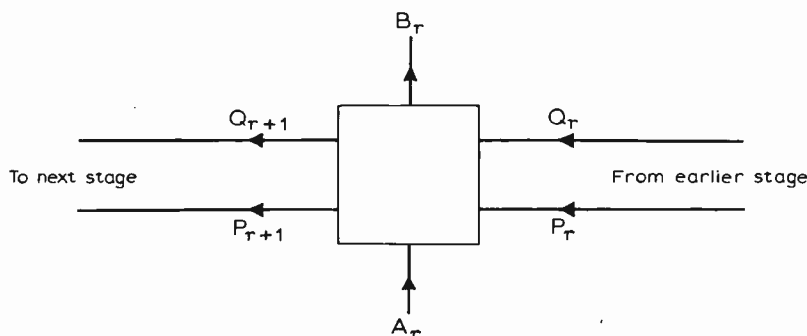


Fig. 3. One block of the array for multiplication by three.

\*City University, London.



The information contained in this table can now be plotted on Karnaugh maps, and the logic functions deduced. The maps, which are shown in Fig. 4, are the same as in Dean's Fig. 3, except for the changes in notation. From these maps it can be seen that:

$$B_r = \bar{A}_r Q_r + A_r \bar{Q}_r$$

or

$$B_r = (\bar{A}_r + \bar{Q}_r)(A_r + Q_r)$$

$$\bar{B}_r = \bar{A}_r \bar{Q}_r + A_r Q_r$$

$$P_{r+1} = A_r P_r + A_r Q_r$$

or

$$P_{r+1} = A_r(P_r + Q_r)$$

$$\bar{P}_{r+1} = \bar{A}_r + \bar{P}_r \bar{Q}_r$$

$$Q_{r+1} = \bar{Q}_r(\bar{A}_r + \bar{P}_r)(A_r + P_r)$$

$$\bar{Q}_{r+1} = Q_r + \bar{A}_r \bar{P}_r + A_r P_r$$

The functions were given first in the sum-of-products form, and each of them could be realised using one OR- and two AND-gates, or else three NAND-gates. Secondly the functions were given in product-of-sums form. In this form they require altogether eight gates for their realisation, either five OR- and three AND-gates, or eight NOR-gates. However, not only  $B_r$ ,  $P_{r+1}$  and  $Q_{r+1}$  are required, but  $\bar{P}_{r+1}$ ,  $\bar{Q}_{r+1}$  and, possibly,  $\bar{B}_r$ . These may be produced by means of inverters, but it may be more economical to produce the complement directly and complement that.\* To see whether this is so expressions for  $\bar{B}_r$ ,  $\bar{P}_{r+1}$  and  $\bar{Q}_{r+1}$  in sum-of-products form have also been given. To produce  $\bar{P}_{r+1}$  with NAND-gates two are required compared with three to produce  $P_{r+1}$ . The former is therefore the more economical course. With the other two output variables there is no difference, so that the total number of gates required may be reduced from nine to eight.

Further economy is possible. The expression for  $\bar{P}_{r+1}$  may be modified to  $\bar{A}_r + A_r \bar{P}_r \bar{Q}_r$  (this may be seen from the map or from the well-known result that  $X + \bar{X}Y = X + Y$ ). When this has been done the term  $A_r \bar{P}_r \bar{Q}_r$  is common to the expressions for  $\bar{P}_{r+1}$  and  $Q_{r+1}$ , so that a further gate may be saved, reducing the number per block to seven. The inverters for  $P$  and  $Q$  may be placed at the input or output of a block. The former course reduces the number of leads between blocks, and this is the arrangement which has been shown in Fig. 5.

**Alternative codings**

In the previous circuit a weighted binary code was used for the carry digit. There are,

\*Zissos and Copperwhite<sup>2</sup> have considered the problem of realising a logic function with gates when the complements of the inputs are not available, and have shown that to design a circuit which is minimal when the complements are available, and add inverters, does not always lead to the most economical solution. Although, in general, their results are applicable to the situation considered here, a systematic procedure for applying them to multiple-output networks has not been worked out, and no attempt has been made to make use of them here.

**Table one**

$A_r$	$P_r$	$Q_r$	$a_r$	$c_r$	$a_r+c_r$	$c_{r+1}$	$B_r$	$P_{r+1}$	$Q_{r+1}$
0	0	0	0	0	0	0	0	0	0
0	0	1	0	1	1	0	1	0	0
0	1	0	0	2	2	1	0	0	1
0	1	1	-	-	-	-	$\phi$	$\phi$	$\phi$
1	0	0	3	0	3	1	1	0	1
1	0	1	3	1	4	2	0	1	0
1	1	0	3	2	5	2	1	1	0
1	1	1	-	-	-	-	$\phi$	$\phi$	$\phi$

$\phi$  denotes an optional value

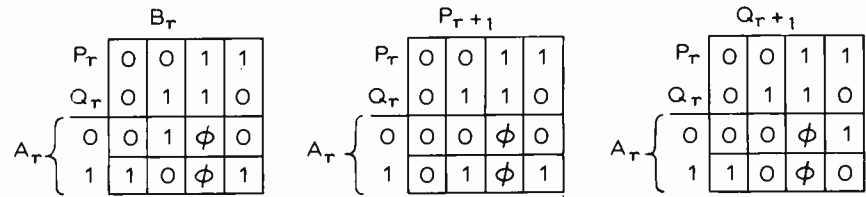


Fig. 4. Karnaugh maps for one block of an array for multiplication by three.

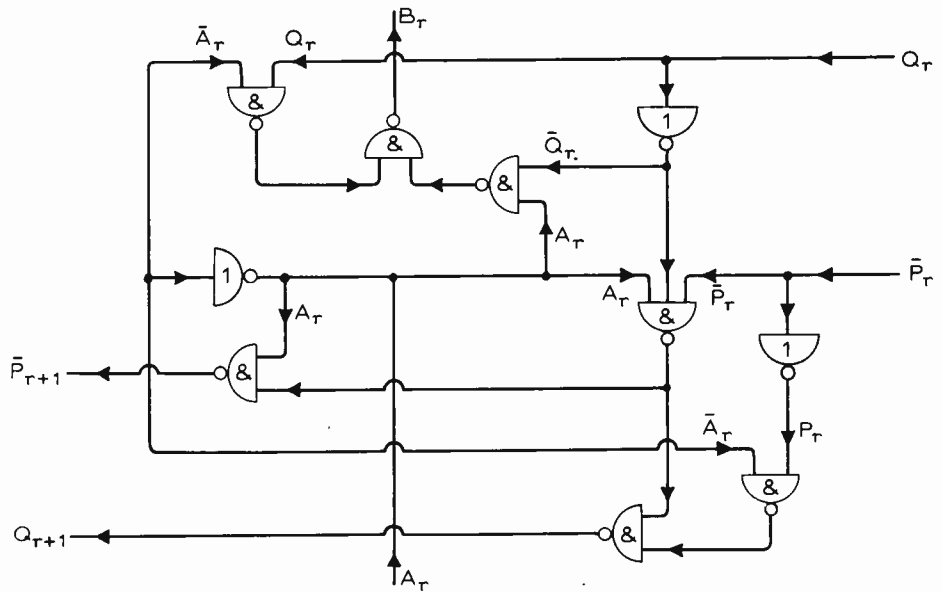


Fig. 5. The logic circuit of a block which will multiply by three.

however, many other ways of coding the carry digit and some of these lead to more economical circuits. The first step is to set out the various possibilities and the second is to distinguish those alternatives which lead to different circuits from those which merely lead to the same circuit differently labelled. It is convenient in setting out the alternatives to make use of Karnaugh maps, arranging the three values of the carry digit, 0, 1 and 2, in various ways in the four spaces of a two-variable map. Leaving one space vacant for the present, the opposite space may be occupied by 0, 1 and 2, giving the three possibilities of Fig. 6(a). The three possibilities of Fig. 6(b) differ from those of Fig. 6(a) only in having  $P_r$  and  $Q_r$  interchanged, so that they lead to designs which are identical, though differently labelled. The three possibilities of Fig. 6(c) are obtained from those of Fig. 6(a) by comple-

$Q_r$	$P_r$	0	1	0	1	0	1
0		0	2	1	2	2	1
1		1		0			0
0		0	1	1	0	2	0
1		2		2			1
0		2	0	2	1	1	2
1		1		0			0

Fig. 6. Coding possibilities, first step.

	$P_r$	0	1	0	1	0	1
$Q_r$		(a)	(b)	(c)			
0		0 2	1 2	2 1			
1		1 $\phi$	0 $\phi$	0 $\phi$			
		(d)	(e)	(f)			
0		0 2	1 2	2 1			
1		1 0	0 0	0 0			
		(g)	(h)	(j)			
0		0 2	1 2	2 1			
1		1 1	0 1	0 1			
		(k)	(l)	(m)			
0		0 2	1 2	2 1			
1		1 2	0 2	0 2			

Fig. 7. Coding possibilities showing all alternatives with some duplication.

menting  $P_r$ , that is, they are the same except that the variable previously called  $P_r$  has been called  $\bar{P}_r$ . In general, since both  $P_r$  and  $\bar{P}_r$  are required, they lead to identical designs. The same applies if  $Q_r$  is complemented.

So far there are only three distinct alternatives. Next it is necessary to decide how to use the spare state. One possibility is not to use it at all. This is what Dean did with the first coding of Fig. 6(a), and it leads to the solution we have already described. On the other hand, the spare state may be used as an alternative way of conveying the information that the carry digit has one of the three values, for example, in Fig. 7(d) when the carry digit is 0 this information may be conveyed by  $P_{r+1}Q_{r+1} = 00$  or  $P_{r+1}Q_{r+1} = 11$ . In Fig. 7(e) the same information is conveyed by  $P_{r+1}Q_{r+1} = 01$  or  $11$ . This means that when  $Q_{r+1} = 1$  the carry digit is 0 whatever the value of  $P_{r+1}$ , so that when the carry digit is 0 the value of  $P_{r+1}$  is optional. Thus the flexibility available as a result of having a spare state has not been lost by assigning to that state a specific message—it has been made use of in a different way.

Fig. 7 has been obtained from Fig. 6(a) by inserting  $\phi, 0, 1$  or  $2$  in the vacant space. There appear to be twelve alternatives but on inspection it may be seen that (f) becomes the same as (e) on complementing  $P_r$ , (l) becomes the same as (k) on complementing  $Q_r$ , and (j) becomes the same as (g) on interchanging  $P_r$  and  $Q_r$  and then complementing  $P_r$ , so that there are only nine alternatives.

**Designs with alternative codings**

Designs for all these alternative codings have been worked out, and the best was found to be (g). It may be noted that this differs from the weighted code only in the use made of the spare state. The table of combinations and the resulting Karnaugh

Table two

$A_r$	$P_r$	$Q_r$	$a_r$	$c_r$	$a_r+c_r$	$c_{r+1}$	$B_r$	$P_{r+1}$	$Q_{r+1}$
0	0	0	0	0	0	0	0	0	0
0	0	1	0	1	1	0	1	0	0
0	1	0	0	2	2	1	0	$\phi$	1
0	1	1	0	1	1	0	1	0	0
1	0	0	3	0	3	1	1	$\phi$	1
1	0	1	3	1	4	2	0	1	0
1	1	0	3	2	5	2	1	1	0
1	1	1	3	1	4	2	0	1	0

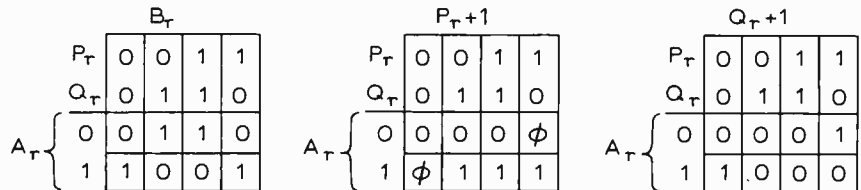


Fig. 8. Karnaugh maps for one block of an array for multiplication by three using an alternative coding.

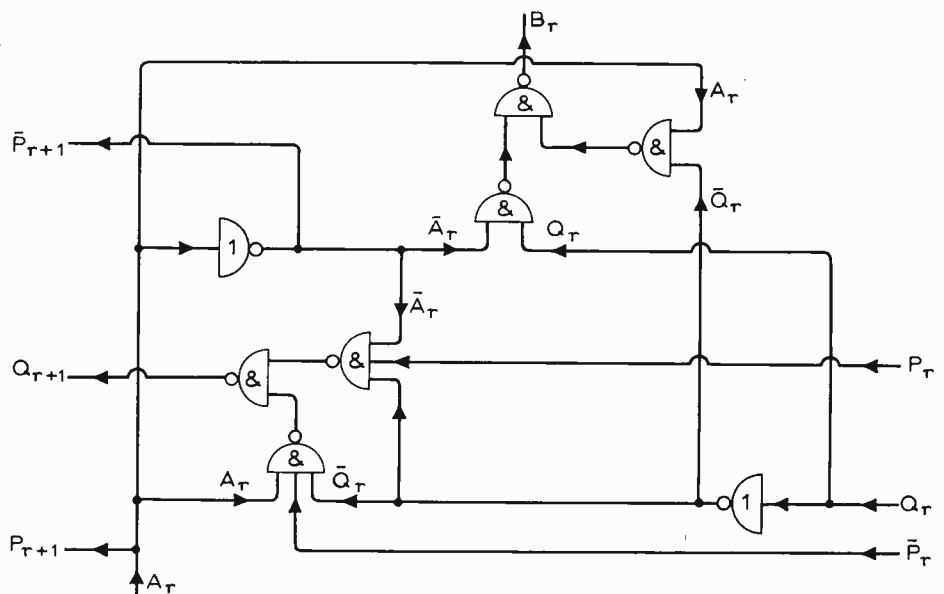


Fig. 9. The logic circuit required when using the alternative coding. Note that fewer gates are now required.

maps are given in Table two and Fig. 8. From these maps:

$$B_r = \bar{A}_r Q_r + A_r \bar{Q}_r$$

or

$$B_r = (\bar{A}_r + \bar{Q}_r)(A_r + Q_r)$$

$$\bar{B}_r = \bar{A}_r \bar{Q}_r + A_r Q_r$$

$$P_{r+1} = A_r$$

$$\bar{P}_{r+1} = \bar{A}_r$$

$$Q_{r+1} = \bar{A}_r P_r \bar{Q}_r + A_r \bar{P}_r Q_r$$

or

$$Q_{r+1} = \bar{Q}_r (\bar{A}_r + \bar{P}_r) (A_r + P_r)$$

$$\bar{Q}_{r+1} = Q_r + \bar{A}_r \bar{P}_r + A_r P_r$$

Since  $P_{r+1} = A_r$ ,  $\bar{P}_{r+1} = \bar{A}_r$ , so only two inverters are required, assuming  $\bar{B}_r$  is not

wanted. If NAND-gates are used, six are required. It is marginally better to produce  $\bar{Q}_{r+1}$  directly and use an inverter to obtain  $Q_{r+1}$ , rather than the reverse, since then only one of the six NAND-gates will have three inputs. The resulting design for one block is shown in Fig. 9.

**REFERENCES**

1. K. J. Dean, "Iterative arrays of logical circuits for performing arithmetic", *Electronic Engineering*, Vol. 40, No. 490 (Dec. 1968).
2. D. Zissos and G. W. Copperwhite, "Further Developments in the Design of Minimal NOR (and NAND) Combinational Switching Circuits for N-Variables", *Electronic Engineering*, Vol. 38, No. 461 (July 1966).

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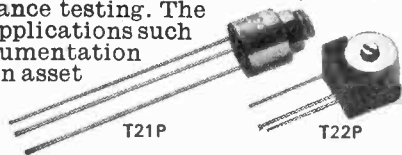
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# Roots and Responses

## Showing how the root technique applies to filter design

by Thomas Roddam

When I began writing this group of articles a few months ago it was because I wanted to discuss the question of why we use sine waves, why we go to a good deal of trouble to make sine waves. The answer turned out to be that it is very easy to produce a perfect sine wave, if you are a mathematician. All you need is inductance, capacitance, a battery and a switch. One thing you must not be is a physicist. I assert that my LC circuit has a sinusoidal current flowing in it and that the frequency is such and such. Call me a liar and I connect a measuring device. A measuring device, however, must load the circuit down and, to some extent affect the frequency. As a mathematician I can use positive feedback to give me infinite input impedance, but I have the problem of keeping the noise energy finite.

The engineer is not driven into this corner. He has real coils and capacitors producing a straightforward complex frequency. He has two quite separate ways of keeping his signal going. In practical circuits they may get a bit mixed up, but essentially they are totally different. In one method the maintaining circuit can be analyzed into a negative resistance which is used to balance out the resistances in the practical LC circuit. Various sorts of a.g.c. circuit are used so that this balance is maintained at a particular level of oscillation. It sounds very easy but it can be a life-time career. Some of the rules are easy to write down. The system must be linear: the negative resistance must appear in the circuit in the same way as the circuit positive resistance. This last rule is normally concealed in a sea of mathematics. The reason behind it is simple. If the circuit loss is, for example, the wire resistance of a coil, and we have a parallel tuned circuit with a parallel maintaining negative resistance, the negative resistance must balance out an admittance term  $R/(R^2 + \omega^2 L^2)$ . The self-adjusting property allows this, but there is still a term in  $R$  in the frequency expression. What happens, in terms of those root diagrams, is that the root is moved bodily sideways to the  $j\omega$  axis. Because  $R$  is temperature dependent, the frequency will also be temperature dependent. Because the frequency displacement is normally happening as we move round the top of the root locus semicircle the change will not be very big, and if we start with a good circuit  $Q$  may not be the most important change. If we

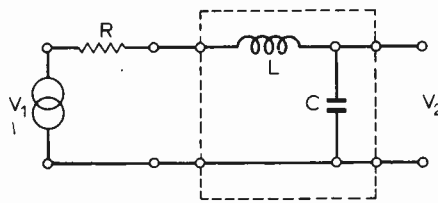


Fig. 1. Simple low-pass filter with high impedance load.

use a series negative resistance and a series LC circuit we should go round to oscillate at  $\omega^2 LC = 1$ . Now, however, any shunt losses must be transformed to series losses.

A quite different method generates the tuned circuit root frequency itself. This is the way we produce substantial amounts of sine wave power and have done since I don't know when. In simple terms a reversing switch, or even a simple short contact duration switch is used to flip energy into the tuned circuit every half-cycle, every cycle, or even, in frequency multipliers, every  $n$  cycles. One common form of this is the familiar square wave inverter with a simple filter.

A class-C oscillator is a fine example of a mix-up. The *on* period of the amplifier moves the root over into the right-hand half of the plane. If the amplifier saturates, of course, back we go to the left. During the *off* period the tuned circuit is aware only of its own complex frequency. The great days of the class-C oscillator were the days of the self-biased system, in which the circuit itself settled the amount of each cycle spent in each mode. If anyone had stopped to work it out they would never have built an oscillator.

The use of roots in the complex plane, that is the use of the complex natural frequencies of circuits, introduced a new age in the design of filter and frequency dependent networks. The old school grew up on the work of Campbell and Zobel. This followed on the real beginnings, with names like Kelvin, Heaviside, Pupin. The Great Eastern, black smoke pouring from her funnels, lays the transatlantic cable. The loading coil made it possible, with the valve amplifier, for the great moment, in 1915, when no fewer than three telephone circuits connected San Francisco to New York and Washington. Four wires, strung on poles. More wires, strung on poles, and

by 1937 there were 140 circuits. *Wireless World* was already being published before it was possible to 'phone across America.

The growth of trunk telephone circuits depended on carrier operation, and this, in turn, depended on filter design. The filter design grew out of the theory of long lines and, in its beginnings, ignored its ends. I suppose that a large number of the filters being built today are still based on the handy summaries of constant- $k$  and  $m$ -derived sections which are to be found in all the reference books. These are slices from a long chain of similar sections, with reactance all the way through like the town's name in a stick of seaside rock. In the simple theory the source and the load matched the filter. In reality source and load were resistive: the calculations were patched up by the use of mismatch loss, interaction loss and other delicate corrections.

The first step away from the assembly kit was the result of examining the reactance network as a whole. The filter, by itself, showed a set of characteristic frequencies at which the reactance was either zero or infinite. The distribution of poles and zeros determined the overall response, apart from the patches. Two problems remained: the effect of the losses of the elements themselves and the effect of the resistive terminations. Cauer and Bode are the great names of the classic lattice network period. Reading system into the random walk of the historical development it was the need to allow for the losses of practical components which opened up the great leap forward. The theorists of finite losses moved into the complex plane.

The move was a rather timid one. The whole line of roots was moved bodily sideways, and ideally for all the elements the value of  $R/L = G/C$  was the same. But the theory had moved from one dimension to two.

Instead of moving from one dimension to two by introducing the resistances associated with each and every reactive component we may just introduce one or two resistances associated with the source and the load. Let us take the simplest circuit worth considering, the simple low-pass network of Fig. 1, fed from a generator of impedance  $R$  and feeding an infinite impedance load. This is a common situation when the load is in fact a high input impedance amplifier.

If you think of the three components as a voltage divider you can write down the proportionality equation

$$\frac{V_1}{R+j\omega L+1/j\omega C} = \frac{V_2}{1/j\omega C}$$

so that

$$\begin{aligned} \frac{V_1}{V_2} &= 1+(R+j\omega L)j\omega C \\ &= 1+j\omega CR-\omega^2 LC \end{aligned}$$

Of course, I should not have used  $j\omega$ . That's the equation for response, but I want a function,

$$G = 1+pCR+p^2LC$$

in which  $p$  can have any value. If we put  $G = 0$  we have

$$LCp^2+CRp+1=0$$

so that

$$p = \frac{-CR \pm \sqrt{C^2R^2-4LC}}{2LC}$$

giving two roots,  $p_1$  and  $p_2$ ,

and  $G = (p-p_1)(p-p_2)$ .

When we take the special case of  $(V_1/V_2)$ , we see that this corresponds to  $p = j\omega$ , so that

$$\frac{V_1}{V_2} = G(j\omega) = (j\omega-p_1)(j\omega-p_2)$$

In Fig. 2 we see these two poles,  $p_1$  and  $p_2$ . We know from our previous discussion that they are complex conjugate, though we see this in the equation above, too. I have assumed that  $4LC > C^2R^2$ , to get them up off the negative real axis.

The term  $(j\omega-p_1)$  is the vector  $l_1$  in Fig. 2, and  $l_2$  is, of course,  $(j\omega-p_2)$ . The response is the product  $l_1l_2$ . It is rather easy geometry to see that this can be described by Fig. 3 instead of Fig. 2. One method of proceeding from this point is to do some more algebra to show how we can plot frequency responses using an electrolytic tank. I have seen a good many discussions of the use of this sort of analogue technique over the years but I have never actually come across anyone who really built networks for systems in this way. I am pretty certain that now I never shall: if the network needs that sort of approach you hire a mathematician, or computer time, or both.

The really conscientious reader may be

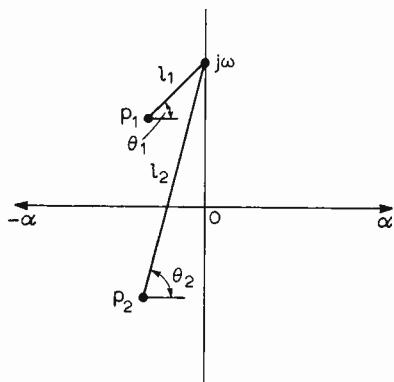


Fig. 2. The poles for the network of Fig. 1.

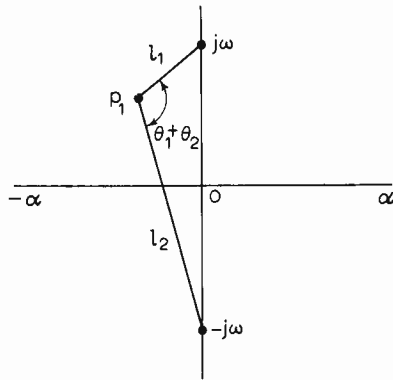


Fig. 3. Another way of getting the quantities in Fig. 2.

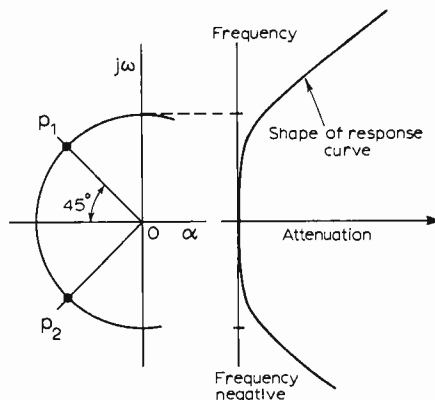


Fig. 4. Position of poles, and network response, sketched sideways compared with usual form, for Butterworth response.

wondering why we have plodded through to

$$\frac{V_1}{V_2} = 1+j\omega CR-\omega^2 LC$$

all over again. Let us get out our Avometers, and measure  $V_1$  and  $V_2$ . Phase angle goes overboard, and all we determine is

$$\left| \frac{V_1}{V_2} \right|^2 = 1+\omega^2(C^2R^2-2LC)+\omega^4L^2C^2$$

This is the equation which describes the behaviour of the network as a frequency-selective network. Last month we considered the network as a frequency-dependent one. This distinction is one which can be very real among designers and it can lead to quite serious communication difficulties. Engineers working on radio frequencies use this network, and the slightly more complicated one with a capacitance at each end, as band-pass impedance transformers. They consider it as a kind of tapped tank circuit, and, very often, do all their calculations at a single frequency, the carrier frequency. Sometimes they regard the circuit as a lumped version of a quarter-wave line. The Campbell-Zobel filter man sees it as a low-pass filter, but the element values used in the r.f. coupling circuits indicate very large mismatch effects. In classical filter theory these are exceedingly tedious to work out, and when they have taken charge completely one loses all feel, one doesn't know what is going on. In fact, we are concerned with situations where one important root,  $p_1$ , is relatively close to the  $j\omega$  axis (should we really call this the  $\omega$  axis?), and the

length  $l_1$  in Fig. 2 takes complete control.

The filter man would like  $|V_1/V_2|$  to stay pretty constant up to the cut-off frequency. This would give him a well-defined pass region. Now  $|V_1/V_2|^2$  depends on  $\omega^2$  and on  $\omega^4$ , and if these are small the  $\omega^4$  term is smaller than the  $\omega^2$  term. Put like that it sounds rather a dubious statement. Let us write

$$\omega^2 LC = \sigma^2$$

Then

$$\left| \frac{V_1}{V_2} \right|^2 = 1+\sigma^2 \left( \frac{C^2R^2-2LC}{LC} \right) + \sigma^4$$

Here  $\sigma^4 < \sigma^2$  so long as  $\sigma < 1$ . We can guess that to make the coefficient of  $\sigma^2$  zero will give us a rather simple way of holding  $|V_1/V_2|$  near unity over a limited range of frequencies. For this condition,

$$C^2R^2 = 2LC, \text{ or } \frac{L}{C} = \frac{R^2}{2}.$$

We now have

$$\left| \frac{V_1}{V_2} \right|^2 = 1+\omega^4 L^2 C^2$$

This is the simplest form of what is called a Butterworth response. The roots of the basic function

$$G = 1+pCR+p^2LC$$

are at 
$$p = \frac{-CR \pm \sqrt{C^2R^2-4LC}}{2LC}$$

and if we substitute  $CR^2 = 2L$  we get

$$\begin{aligned} p &= \frac{-CR \pm \sqrt{-C^2R^2}}{2LC} \\ &= \frac{1}{2LC} [-CR \pm jCR] \end{aligned}$$

These two poles lie in the positions shown in Fig. 4. Suppose now that we add a capacitance across the input end of the network. In the  $p$  form the ratio  $V_1/V_2$  is now:

$$\frac{V_1}{V_2} = 1+p(C_1+C_2)R+p^2LC_2+p^3LC_1C_2R$$

The Butterworth, or maximally flat, response takes the form, in terms of  $\omega$ , of

$$\left| \frac{V_1}{V_2} \right|^2 = 1+g^2\omega^6$$

It is not an insuperable task to substitute  $j\omega$  for  $p$ , separate out the  $j$  terms, square up and solve the equations. There will be two of these, to make the  $\omega^2$  and  $\omega^4$  terms vanish. We can proceed in a rather different way. We are substituting  $j\omega$  for  $p$ , and so the network response function could be written

$$1+g^2(p/j)^6$$

This is an expression which must break down into a group of factors of the form  $(p-p_k)$ . To find the values of  $p_k$  we write

$$(1+g^2(p/j)^6) = 0$$

or 
$$g^2(p/j)^6 = -1$$

Here the mathematician enters. We know that if

$$x^2 = -1$$

we have  $x = \pm j$ .

What happens if  $x^3 = -1$ , or  $x^4 = -1$ , or  $x^n = 1$ ? It is not enough to say that  $x = -1$  if  $x^3 = -1$ . We expect three roots. The form 1 means unit whatever, but let us take it as a section of a line, a unit movement in a defined direction, and  $-1$  is the same length, the other way. Displaced, or rotated, we say, by  $180^\circ$ . For  $x^2 = -1$  we take two bites, moving  $90^\circ$  and then  $90^\circ$  (or  $-90^\circ + -90^\circ$ ). For  $x^3 = -1$  we can take  $(-180^\circ) + (-180^\circ) + (-180^\circ)$ , one and a half times round the compass. We can also try  $60^\circ + 60^\circ + 60^\circ$  round, and go round clockwise or anticlockwise. For higher orders,  $x^n$ , we are like a legendary north country figure, whose hat-band went nine times round and wouldn't tie. In case you are confused, he was going to a funeral. In fact, if we settle for the even functions, with

$$g^2 x^{2n} = -1, \text{ we get}$$

$$x_k = jg^{-1/n} \exp(j(2k-1)\pi/2n)$$

where  $k$  is  $1, 2, \dots, 2n$ .

These roots are arranged round a circle of radius  $g^{-1/n}$ , and if we collect only the roots for  $k \leq n$  they all lie in the left-hand half of the plane. For reasons of symmetry the absolute value of the product of the factors produced by the right-hand roots is equal to that of the left-hand roots. We therefore get a set

$$(p-p_1)(p-p_2) \dots (p-p_n) = \Pi(p)$$

and

$$|1 + g^2 \omega^{2n}| = g^2 |\Pi(j\omega)|^2$$

This means that  $g|\Pi(j\omega)|$  can be taken to give us, in the form we are using,  $|V_1/V_2|$ . And as  $|1 + g^2 \omega^{2n}|$  is the Butterworth response term, the roots are found from the equation for  $x_k$ . Since it is not too easy to think in terms of the exp function, we convert it to sines and cosines:

$$p_k = g^{-1/n} [-\sin(2k-1)\pi/2n + j \cos(2k-1)\pi/2n]$$

$$1 \leq k \leq n$$

We, at the moment, are interested in the case  $n = 3$ , and so we have angles of

for $k = 1$	2	3
angle = $\pi/6$	$3\pi/6$	$5\pi/6$
$30^\circ$	$90^\circ$	$150^\circ$

All the roots, including those in the right-hand half of the plane, are shown in Fig. 5. Compared with Fig. 4, we see that adding one reactance we have added one root. Symmetry about the vertical axis implies that with  $2 \times 3$  roots we must get one of the left-hand plane roots on the real axis.

Although this is still a pretty simple network it can be used to give some insight into circuit behaviour. The root  $p_1$  in Fig. 5 is closer to the frequency axis than is  $p_1$  in Fig. 4. The circuit, so far as this pole (and its mate  $p_3$ ) is concerned, is more like a tuned circuit. It has, in other language, a higher  $Q$ . The root  $p_2$ , however, corresponds to an RC circuit. The roots taken together are the combination of an underdamped circuit and an overdamped circuit. This is a technique well-known in i.f. amplifier design. Indeed, there are two different

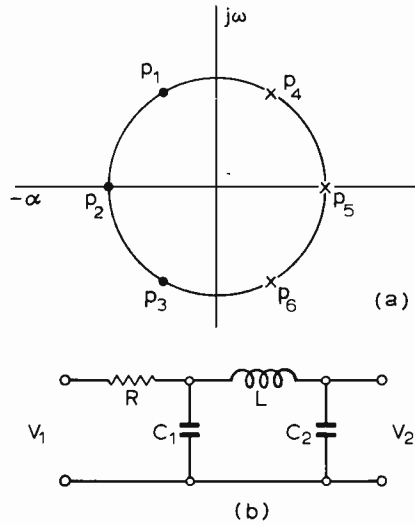


Fig. 5. (a) The six roots, of which only  $p_1, p_2$  and  $p_3$  are needed, for studying  $|V_1/V_2|$  for network (b).

ways of getting the effect. One is by choosing the  $Q$  values of the i.f. transformers, which are all tuned up to the same frequency. The other is by stagger tuning. In staggered systems each stage produces one root, and they are set around a semicircle whose centre is at the band centre and whose radius is the 3 dB bandwidth. Design is obviously very easy now. For a twenty stage monster, plot out the 20 roots, find the frequency and damping for each and tune them up individually. All you need is sine and cosine tables.

The modern thing, as you cannot help knowing, is active filters. I showed last month how a simple two-stage amplifier with two RC circuits could have its roots moved about in the left-hand half of the plane by varying the feedback. Each circuit of this kind can be used to put a pair of roots wherever we like. By tandem connection you can have all the roots you want, where you want. I do not propose to enter the active filter area except to point out that it does rely much more on root-thinking. For younger readers I must add that it is only really sound engineering now that cheap amplifiers are possible. Around 1950, with the transistor just on the way, a rough cost of using a valve was £20, allowing for power consumption and replacements over the life of the equipment. In present terms that would be about £50. I have not done the sum for a transistor, but I will guess £0.5. Amplifiers are much cheaper, nickel is much dearer, and inductors are no longer the economical answer.

Let us go back to our simple low-pass filter. For the designer the advantage of the Butterworth response is obvious: it gives some very easy mathematics. Unfortunately

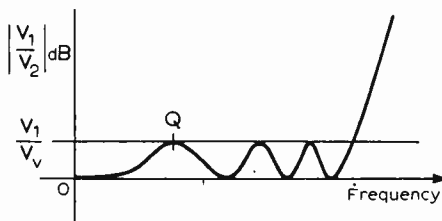


Fig. 6. Typical 'good' filter characteristic.

the customer, whether he is an outsider or just another section or individual inside the same organization, does not really care if the filter designer has an easy life. He wants the best performance, even if that means that you get the best headaches. He knows that a rather wider pass-band for a given tolerance across the band will be obtained if the response rises slightly towards cut-off and then drops away. A very coarse picture of this appeared as Fig. 10(a) in last month's article. Fig. 6 shows a response with a number of peaks and valleys in the pass-band. The important thing to notice is that it is fitted firmly into the space between the zero loss line and the  $|V_1/V_0|$  line. The object of the exercise is to use the tolerance as efficiently as possible. It is quite fair to use a slightly different version of this, the section to the right of the point  $Q$ , and the special case we have been looking at has only one—what shall we call it, half-cycle?—to the right of  $Q$ .

What about the mathematics? It was done for us nearly 100 years ago. The functions we want are called the Tchebyscheff polynomials, and they are good, not only for designing networks, but also for promoting vigorous argument, not about mathematics but about spelling. The Russian letter Ч is the problem, at the beginning, and problems go right through to the end: is it "eff" or "ev"? My own guess is that confusion really set in when the French speakers in St. Petersburg turned into the English students in Leningrad. Whether you are old-fashioned, like me, or a modern who writes Chebishev, many of the texts write  $T_n(x)$  for the function. The moderns are thus left with the sort of confusion I feel when old Mr. Weller calls out "Spell it with a wee, my lord".

When we turn to using the  $T$  function we write the basic equation in the general form

$$\left| \frac{V_1}{V_2} \right|^2 = \{1 + g^2 [T_n(\omega)]^2\} N_0^2$$

Where  $N_0$  is the value of  $|V_1/V_2|$  at  $\omega = 0$ . All we need to know now is what the form of  $T_n(\omega)$  will be.

By an analytical approach we get

$$T_n(\omega) = \cos(n \cos^{-1} \omega)$$

which is neat but not frightfully convenient.

Fortunately the expression has been expanded for us, in quite a number of publications. As a polynomial,

$$T_n(\omega) = 2^{n-1} \left[ \omega^n - \frac{n}{2^2} \omega^{n-2} + \frac{n(n-3)}{2^4} \omega^{n-4} - \frac{n(n-4)(n-5)}{2^6} \omega^{n-6} \right]$$

and so on until the term  $\omega$  or  $\omega^0$  is reached. For our simple little filter,  $n = 4$ , and we have

$$T_4(\omega) = 8(\omega^4 - \omega^2 + \frac{1}{8}) = 1 - 8\omega^2 + 8\omega^4$$

If  $\omega = 0$  this is unity: if  $\omega$  is large, it is very large indeed: it has one minimum at the response peak, and to find this we differentiate, and get

$$32\omega^3 = 16\omega$$

or

$$\omega^2 = \frac{1}{2}$$

Then  $T_4(0.7) = 1 - 4 + 2 = -1$ , as we might have guessed from the form  $T_n = \cos(n \cos^{-1} \omega)$ .

The coefficient  $g$  fixes the size of the ripple and if we choose a value of  $g$  we can write

$$1 + \omega^2(C^2R^2 - 2LC) + \omega^4L^2C^2 = N_0 [1 + g^2 - 8g^2\omega^2 + 8g^2\omega^4].$$

Solving this equation is always tedious, because specification writers will choose round numbers of decibels, giving very unround values of  $g$ . There are, however, charts and tables available. We, in thinking about roots, will write  $\omega = p/j$ . We use the equation

$$T_n(\omega) = \cos [n \cos^{-1} (p/j)],$$

and since for the roots

$$1 + g^2(T_n)^2 = 0$$

we must have  $T_n = \pm j/g$ , giving us

$$\cos [n \cos^{-1} (p/j)] = \pm j/g.$$

If we now put  $\cos^{-1} (p/j) = \alpha - j\beta$  we can solve this equation. I do not propose to write down all the mathematics, even though it means that you must either do it yourself or take the conclusions on trust. The conclusions are that the roots lie on an ellipse. This seems fair enough when you think that the circle is just a special kind of ellipse, in which the equation

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

is simplified by making  $a = b$  and losing one control factor. The position of the roots on the ellipse is found by the following procedure. We draw a semi-circle of radius

$$\cosh [1/n \sinh^{-1} (1/g)]$$

This looks complicated, but it consists only of things you look up in tables. If, for example,

$$g = 0.1 \text{ and } n = 2$$

$$\sinh^{-1} 10 \approx 3$$

$$\cosh 3/2 = \cosh 1.5 = 2.35$$

We also need, while the tables are open,

$$\sinh (1/n \sinh^{-1} (1/g)),$$

and  $\sinh 1.5 = 2.13$

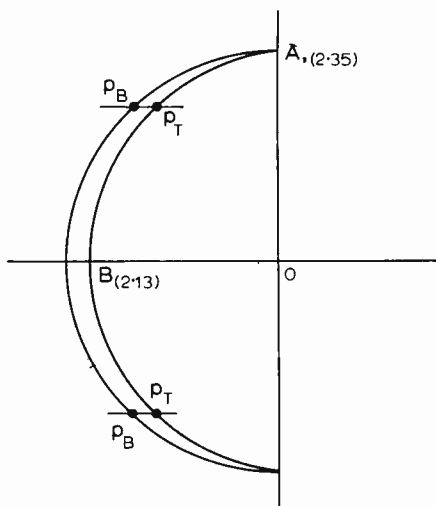


Fig. 7. Butterworth and Chebyshev poles.

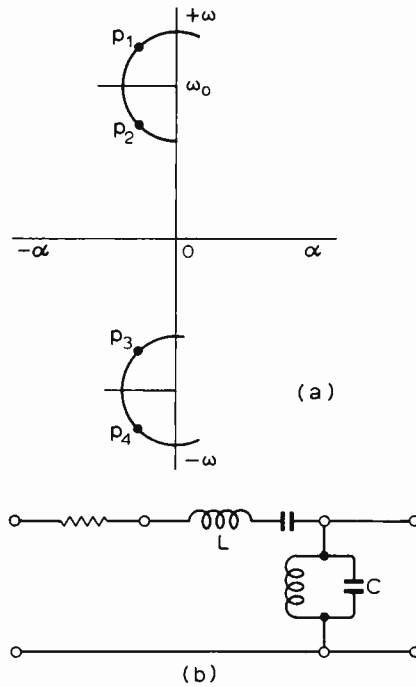


Fig. 8. A set of four roots (a), and the circuit (b).

Now we can draw Fig. 7. We mark off the point  $A$  at a distance 2.35 and draw the semicircle. Then we mark  $B$  at  $-2.13$ , and construct the ellipse. Next, put in the evenly spaced Butterworth roots round the circle. Finally, draw lines parallel to the  $\alpha$  axis to intersect the ellipse at the Chebyshev poles. With only a small ripple the ellipse is nearly a circle, and the roots have not moved very far. The more the ripple the flatter the ellipse. The picture for more complicated networks is just as easy to draw. We have two roots in the left-hand half of the plane: if we take  $n = 20$  we shall get 20 roots, evenly spaced at  $9^\circ$  apart, and it is just as easy to look up  $\cosh 3/20$  as to look up  $\cosh 3/2$ .

The active filter designers, free to move their roots about, can equally get the  $T$  response. There thus remain two topics needing mention. Let us suppose that we place roots at the four points shown in Fig. 8. The pair  $p_1$  and  $p_2$  are positioned on a circle with its centre at  $\omega_0$ . If this is a small circle, on the overall scale,  $p_3$  and  $p_4$  are so far away that we can forget them. We can convert the circle into an ellipse, if we wish. In the region not too far from  $\omega_0$  the response shape will be of the kind shown in Fig. 4, except that negative frequencies of  $(\omega - \omega_0)$ . The design, whether for a  $B$  response or a  $T$  response, follows the low-pass procedure to establish  $L$  and  $C$  in the network of Fig. 8(b). When these have been found the centre frequency is moved to  $\omega_0$  by tuning these elements separately to  $\omega_0$  by the additional  $C$  and  $L$ . Analysis shows that it is not  $(\omega - \omega_0)$  we must consider, but

$$\omega_0 \left( \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right)$$

This correction automatically takes into account the effect of  $p_3$  and  $p_4$ .

A feature of this way of analysing the circuit of a band-pass system is that it

indicates quite clearly why we are liable to get asymmetry with filters of large fractional bandwidth. In a diagram of the scale I have used it is pretty obvious that at  $\omega_0/2$  the root  $p_3$  is just about as important as the root  $p_1$  but quite a bit more important than  $p_4$ . There is all the makings of asymmetry in this arrangement.

The networks we have analysed have the constant- $k$  behaviour, the steady rise of attenuation outside the pass-band. To produce the sort of characteristic we normally use we want to add some peaks of attenuation, as we do with  $m$ -sections in classical theory. Our roots have been at the zeros of the function  $|V_1/V_2|$ : now we must consider that infinities, the poles, of  $|V_1/V_2|$ . We can actually place these on the frequency axis if we use resistance-balancing circuits, and they will normally be very close to this axis, because we will go for a high  $Q$  at the suppression peaks. In the stop band we can go for Tchebysheff behaviour of the inverse kind, with all the troughs at the same level. Again  $RC$  networks combined with amplifiers will give us what we want, but now we must be sure that in bringing a root near to the axis we do not let it stray into the right-hand half of the plane.

From this point on the mathematics gets unwieldy. Once that happens the analysis is a formal operation. The object of this article is to work with circuits which are familiar, so that the root technique is seen to work. For complex circuits you need faith, and hard work. I hope I have provided some foundations for the faith.

## Books Received

**Beginner's Guide to Radio**, by Gordon J. King, is an updated (entirely rewritten) version of F. J. Camm's "A Beginner's Guide to Radio". The twelve chapters treat, by simple physical theory, the fundamental principles of electricity and magnetism, radio waves, and modulation. A simple explanation is given of how valves and transistors function in receivers and transmitters. Stereo radio is introduced, and hi-fi reproduction is given a very good explanation, again in very simple terms. A comprehensive list of circuit symbols is given at the front of the book with abbreviations, units, symbols and standard frequency ranges, at the back. Pp.190 and an index. Price £1.

Butterworth & Co. (Publishers) Ltd, 88 Kingsway, London W.C.2.

**Telecommunications Pocket Book**, edited by T. L. Squires, is written in twelve chapters, each by an expert in the field concerned. An attempt has been made to give a broad outline of each aspect of telephony, television, telex, data communication etc. The first chapter, "Communications in the Modern World: an Introduction", gives coherence to the more specialized chapters which follow. Pp.139 with a 4-page index. Price £1 4s.

Butterworth & Co (Publishers) Ltd, 88 Kingsway, London W.C.2.



# Signal Monitoring Networks

## Simple design formulae for rapid evaluation of the basic requirements of monitoring systems

by A. E. Crump\*

The basic problem of monitoring either a.c. or d.c. signals is, that in order to do so, some energy has to be absorbed by the monitoring device. Thus the presence of a monitor modifies the value of the monitored quantity.

Methods for determining whether a passive monitoring device would be suitable for a given application are described, and also the basic methods for calculating amplifier performance should an amplifier be necessary. The design of a monitor circuit is approached by fixing four of the five interrelated parameters shown below and calculating the fifth.

The interrelated parameters are:

Signal level in bearer ( $P$ ).

Characteristic impedance of bearer ( $R_0$ ).

Maximum insertion loss tolerable in bearer circuit ( $l$ ).

\*The Plessey Co., Ltd.

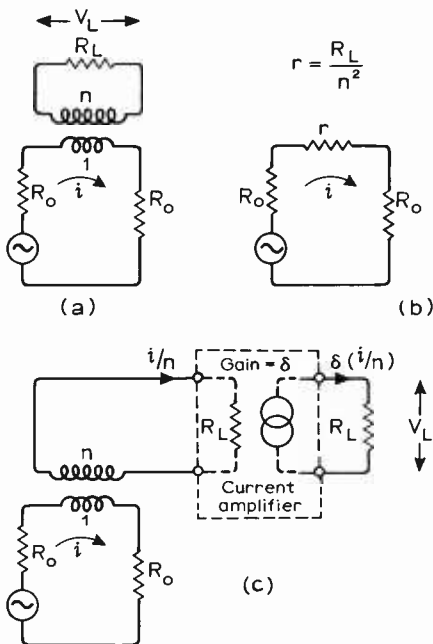


Fig. 1. (a) Current monitor (passive); (b) equivalent primary circuit; (c) method of introducing gain. The input impedance of the amplifier need not equal  $R_L$ , but if not, the calculations must be repeated using the input impedance in place of  $R_L$  in the formulae.

Output level required from monitor ( $V_L$ ).  
Load impedance presented to monitor output ( $R_L$ ).

For our purpose  $P$  and  $l$  are expressed in dB,  $V_L$  in volts, and  $R_0$  and  $R_L$  in ohms.

### Current (series) mode

Figure 1(a) shows the arrangement for using a current transformer to produce the necessary output voltage across  $R_L$ . Figure 1(b) shows the equivalent impedance of the transformer ( $r$ ) in series with the bearer circuit.

The insertion loss incurred by the inclusion of  $r$  in the signal path can be obtained from the established expression:

Insertion loss

$$= \frac{\text{Power in } R_0 \text{ with } r \text{ short-circuit}}{\text{Power in } R_0 \text{ with } r \text{ in circuit}}$$

$$\text{i.e. } l = 20 \log_{10} \left( 1 + \frac{r}{2R_0} \right) \text{ dB.}$$

But according to transformer theory  $r = \frac{R_L}{n^2}$ ,

$$\text{also } V_L = \left( \frac{i}{n} \right) R_L.$$

By substitution and transposition we obtain the formulae:

$$P = 10 \log_{10} \left[ \frac{V_L^2 (10^3)}{\{ \text{antilog}_{10}(l/20) - 1 \} 2R_L} \right] \text{ dBm} \quad (1)$$

$$l = 20 \log_{10} \left[ 1 + \frac{R_L}{2(n^2)R_0} \right] \quad (2)$$

$$n = \sqrt{\left[ \frac{R_L}{2 \cdot R_0 \cdot \{ \text{antilog}_{10}(l/20) - 1 \}} \right]} \quad (3)$$

$$V_L = \sqrt{\left[ 2 \cdot R_L \cdot \left\{ \text{antilog} \left( \frac{P}{10} \right) \right\} \left\{ \text{antilog} \left( \frac{l}{20} \right) - 1 \right\} 10^{-3} \right]} \quad (4)$$

$$R_L = \frac{V_L^2 (10^3)}{2 [ \text{antilog } P/10 ] [ \text{antilog } (l/20) - 1 ]} \quad (5)$$

Having the expressions (1) to (5) it is now possible to substitute known parameters and obtain a guide regarding the validity of the requirement in hand.

*Example 1.* Consider a system similar to Fig. 1(a) in which the signal level of +18 dBm in 75  $\Omega$  is required to produce 6 V r.m.s. across  $R_L$ . What transformer turns ratio is required. What is the value of  $R_L$  required to guarantee 6 V output without exceeding the maximum permissible insertion loss of 0.3 dB?

$$\left. \begin{array}{l} P = +18 \text{ dBm} \\ R_0 = 75 \Omega \\ l = 0.3 \text{ dB} \\ V_L = 6 \text{ V} \end{array} \right\} \begin{array}{l} \text{From (5) } R_L = 8.15 \text{ k}\Omega \\ \text{(preferred value } 8.2 \text{ k}\Omega) \\ \text{From (3) } n = 39.5. \end{array}$$

It is possible thus to satisfy the requirement provided that the output load resistance is 8.2 k $\Omega$  and a transformer turns ratio of 39.5 to 1 is used. The high turns ratio precludes use above about 150 kHz because of the practical problems of producing the transformer. The turns ratio would be smaller, of course, if a higher insertion loss figure were permissible.

*Example 2.* It is required to produce 6 V across a 5000- $\Omega$  load without exceeding 0.3 dB insertion loss in the bearer circuit which is 75  $\Omega$  characteristic resistance. What turns ratio and power level would be required to achieve this?

$$\left. \begin{array}{l} R_L = 5000 \Omega \\ R_0 = 75 \Omega \\ l = 0.3 \text{ dB} \\ V_L = 6 \text{ V} \end{array} \right\} \begin{array}{l} \text{From (1), minimum power} \\ \text{required} = +20 \text{ dBm} \\ \text{From (3), turns} \\ \text{ratio} = 30.8. \end{array}$$

*Example 3.* It is required to produce a 6 V signal across a 5000- $\Omega$  load without exceeding 0.3 dB insertion loss, for a signal level of 0 dBm in 75  $\Omega$ . Is this possible?

From (3),  $n = 952$ . This is an unrealistic transformer ratio, therefore some amplification is necessary. Now assume that a practical ratio for the transformer at the frequency under consideration is  $N$ , then the current amplification required is  $\delta = \frac{952}{N}$  and the system would appear as

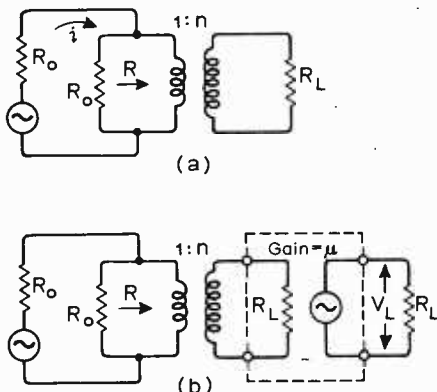


Fig. 2. (a) Voltage monitor (passive); (b) method of introducing gain. As is the case of the current monitor in Fig. 1, if the impedance of the amplifier does not equal  $R_L$  the calculations should be repeated using the input impedance in place of  $R_L$ .

in Fig. 1(c) where  $\delta$  = current gain of amplifier.

**Voltage (shunt) monitoring**

The criterion here is to present a high impedance across the bearer rather than a low impedance in series with it.

Referring to Fig. 2, the insertion loss due to the addition of  $R$  can be expressed as:

$$l = 20 \log_{10} \left( 1 + \frac{R_0}{2R} \right) \text{dB} \quad (6)$$

Proceeding in the same manner as in the series case:

$$R_L = \frac{n^2 R_0}{2[\text{antilog}(l/20) - 1]} \quad (7)$$

$$P = 10 \log_{10} \left[ \frac{(10^3) V_L^2}{2R_L \{ \text{antilog}(l/20) - 1 \}} \right] \text{dBm} \quad (8)$$

$$n = \sqrt{\left[ \frac{2R_L \{ \text{antilog}(l/20) - 1 \}}{R_0} \right]} \quad (9)$$

$$V_L = \sqrt{\left[ \text{antilog}\left(\frac{P}{10}\right) \left\{ \text{antilog}\left(\frac{l}{20}\right) - 1 \right\} 2R_L (10^{-3}) \right]} \quad (10)$$

The versatility of these formulae is comparable to that of the "series" expressions and examples could be given as before. Let us however consider a case where a passive device is insufficient, i.e. the voltage analogy to example (3).

Example 4.

$$\left. \begin{array}{l} R_0 = 75 \Omega \\ R_L = 5000 \Omega \\ l = 0.3 \text{ dB} \\ V_L = 6 \text{ V r.m.s.} \\ P = +10 \text{ dBm} \end{array} \right\} \begin{array}{l} \text{From (9) } n = 2.16 \\ \text{From (10) } V_L = 84 \text{ mV} \end{array}$$

A voltage amplifier is necessary with input

impedance of  $5000 \Omega$  and voltage gain of  $\frac{6 \text{ V}}{84 \text{ mV}} = 71.4$ .

**Effect of monitoring on return loss**

Now the return loss =  $20 \log_{10} \frac{R_0 + Z}{R_0 - Z}$  or

$$20 \log_{10} \frac{R_0 + Z}{Z - R_0} \text{ (dB) where}$$

$R_0$  = Characteristic resistance of bearer  
 $Z$  = load resistance

$$\left\{ \begin{array}{l} \text{For series case } Z = R_0 + (r + jx) \\ \text{For parallel case } Z = R_0 \parallel R(jx) \end{array} \right\}$$

$\therefore$  for current monitoring (ignoring reactance):

$$\text{return loss} = 20 \log \left( 1 + \frac{2R_0}{r} \right) \text{ (dB)} \quad (11)$$

and for voltage monitoring (ignoring reactance):

$$\text{return loss} = 20 \log \left( 1 + \frac{2R}{R_0} \right) \text{ (dB)} \quad (12)$$

† The symbol  $\parallel$  is coming into use with the meaning "in parallel with". Thus,  $R_1 \parallel R_2 = R_1 R_2 / (R_1 + R_2)$ .

## Announcements

The British Amateur Electronics Club is holding its fifth annual exhibition of electronic games from July 25th to August 1st at the Shelter on the Esplanade at Penarth, Glamorgan.

The two British subsidiaries of Tektronix Inc.—Tektronix U.K. Ltd and Telequipment Ltd—became a single company, Tektronix U.K. Ltd, on May 1st with two operating units. The Telequipment Division, with Bob Groom as managing director, will remain at Southgate and the Tektronix Division, with Harry Sellers as managing director, will continue to operate from Harpenden.

Lyons Instruments Ltd, Hoddesdon, Herts, have been appointed exclusive U.K. representatives for Frequency Electronics Inc, of Long Island, New York, and their subsidiaries Atomichron Inc, and FKS Communications Inc. Frequency Electronics design and manufacture high-stability frequency standards, digital clocks, digital phase comparators, standard frequency distribution amplifiers and a range of high-stability crystal oscillators. Lyons Instruments have also been appointed exclusive U.K. representatives for TAU-TRON Inc, of Massachusetts, U.S.A., manufacturers of a range of data generators and digital signal generators.

Techmation Ltd, 58 Edgware Way, Edgware, Middx HA8 8JP, have been appointed sole agents in the U.K. and Eire for the range of silicon PIN photodiodes and light measuring instruments manufactured by United Detector Technology, of Santa Monica, California.

Data Recognition Ltd has appointed Teleprint GmbH of Frankfurt, as exclusive distributor

in West Germany for their optical mark reading equipment and systems.

The newly formed Hitachi Sales (U.K.) Ltd, of 10th Floor, Winchester House, London Wall, London E.C.2, has announced the cessation of the exclusive U.K. distributorship of Hitachi radio receivers by Lee Products.

The electronics division of Union Carbide Ltd has agreed to sell to Solidev Ltd (the U.K. subsidiary of Solitron Devices Inc.) their semiconductor operation based at Aycliffe, Co. Durham.

GEC-Elliott Space and Weapon Systems Ltd, will in future be known as Marconi Space and Defence Systems Ltd.

Pye of Cambridge Ltd are to establish a marketing company, Pye Business Communications Ltd, to sell, hire and service a comprehensive range of audio and video products.

West Hyde Developments Ltd has moved to new works and sales offices at Ryefield Crescent, Northwood Hills, Northwood, Middx HA6 1NN. Tel: Northwood 24941/26732.

Flann Microwave Instruments Ltd, of Kingston-upon-Thames, Surrey, have moved to a new factory and laboratories at Dunmere Road, Bodmin, Cornwall. Tel: Bodmin 3161.

Hayden Laboratories Ltd, East House, Chiltern Avenue, Amersham, Bucks, have opened an audio equipment showroom, despatch and service department at 12/13 Poland Street, London W1V 3DE. Tel: 01-734 3748.

The communications division of Redifon Ltd, has developed a 100-W s.s.b. military radio station, and an order for the Royal Air Force, valued at £156,000 has been completed. The radio station is all solid-state and designed for mobile or transportable use.

Marconi Instruments Ltd has received an order valued at approximately £80,000 from the Post Office to supply pulse-code modulation test equipment. The order includes pattern generator and selective level measuring sets and regenerator testers.

The South African Post Office has placed an order with Plessey for the supply of eight 10-kW h.f. transmitters. The transmitters are self tuned and cover the frequency band 2-30MHz and are intended for point-to-point and ground-to-air operation.

The Marconi Aeronautical Division has been awarded a contract worth more than £250,000 by the Yugoslav Air Force for the installation of AD370 automatic direction finders.

F. C. Lane Electronics Ltd, has moved from Albion Road to Slinfold Lodge, Horsham, Sussex. Tel: Slinfold 661.

U.K. Solenoid Ltd, of Hungerford, Berkshire, manufacturers and distributors of Blue Line rotary switches have opened a London office at Bondway House, 3/9 Bondway, S.W.8. Tel: 01-735 8859.

The Tripletone Manufacturing Co. Ltd, has moved from 241a The Broadway to Factory No.1, 138 Kingston Road, Wimbledon, London S.W.19. Tel: 01-542 1189.

Farnell-Tandberg Ltd, has moved to Farnell House, 81 Kirkstall Road, Leeds LS3 1HR. Tel: Leeds 35111.

Mordaunt-Short Ltd, has moved from London, to The Courtyard, Heath Road, Petersfield, Hants. Tel: Petersfield 4761.

# New Products at the I.E.A. Exhibition

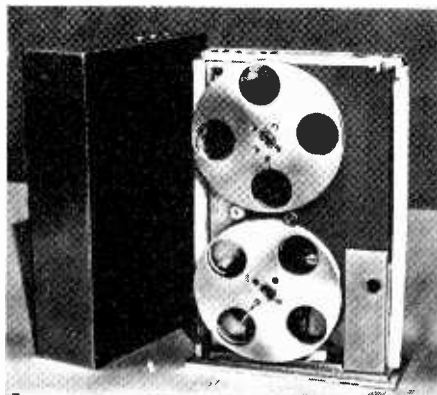
The International Instruments, Electronics and Automation exhibition held at Olympia, London, from 11th-16th May attracted 950 exhibitors with more than 20% coming from overseas. In a statement at the close of the exhibition, chairman William Logan described it as "yet again a record breaker". He was referring to the overseas attendance figures which were 9,658. Total attendance was fractionally down on 1968 at 110,266. Opened officially by Mr. Anthony Wedgwood Benn, Minister of Technology, the show was looked to by British companies to give a boost to business in the electronics export trade. Computer manufacturers in particular, who boast a growing export output, had millions of pounds-worth of equipment on display. These were mostly medium or small size computers, in the £50,000-£120,000 cost bracket, designed for process and production control. Computer aided design was featured by many exhibitors.

A general feature of the many types of measuring instruments on display was their high order of accuracy, a requirement increasingly called for by industry. The demand too for professional class batteries to power the growing number of self-contained instruments and compact communications equipment was met by several exhibitors. Rechargeable batteries are in big demand and a German company was showing a conventional lead-acid accumulator in a form as versatile as an ordinary dry battery. It will also withstand gross ill-treatment. The widening use of electronics in medicine was evidenced by analytical equipment, and instruments for early warning of incipient tumours and high-speed blood sampling. Developments in devices and components for consumer use underlined the way industry is working towards cheaper and more reliable domestic colour receivers and transmitters. There were also several new materials such as self-lubricating plastics and new laminates for printed circuits.

Forty-five American companies with the backing of the U.S. Department of Commerce were combined in a large United States exhibit. Although most of these had contributed to the Apollo space programme, they were said to be taking a "hard sell" approach to the European market and were not engaged on a "national prestige" exercise. "The I.E.A. is a highly effective merchandising device," we were told by their organizers. So much was to be seen that to attempt a general survey of new equipment was far too intimidating. Instead, we have selected a few of the items which are likely to be of particular interest to our readers, brief details of which are given in the pages which follow.

## Miniature Tape Recorder

The world's smallest two-hour tape recorder was the claim made by AIM Electronics for the feature exhibit on their stand. This miniature tape recorder



combines many conventional recorder facilities, such as fast forward wind and fast and slow rewind, in a case measuring only  $80.3 \times 122.5 \times 28$  mm and weighing 468g. By means of a signal operated clip-on unit spasmodic readings can be recorded over a period as long as two years without attention. The recorder is particularly suitable for data collection in arduous environments or small places. It has a remote on/off switch and automatic switch-off when the tape runs out. Tape reels are 56mm in diameter and tape speed is  $24\text{mm/s} \pm 3\%$ . Frequency range is 300Hz to 3kHz; wow and flutter better than 1.2%. Input is via a  $5k\Omega$  microphone and normal speech can be recorded within a range of 6 metres. External connections are made via screw-in jacks. AIM Electronics Ltd, P.O. Box 10, Cambridge.

**WW 328 for further details**

## Resistor Kit

Electrosil were showing their C3 resistor (the smallest glass-tin-oxide) in a designer's pack. The new kit, made in Perspex, measures  $380 \times 100 \times 65$  mm and contains 600 resistors in a range of 30 values from  $10\Omega$  to  $150k\Omega$ . The resistors are held in clearly labelled tubes making for simple selection of the required component. Electrosil Ltd, Pallion, Sunderland, Co. Durham.

**WW 327 for further details**

## Measuring Amplifier, Filter and Frequency Analyser

Brüel & Kjaer, Denmark, has introduced a new series of measuring amplifiers and octave/third-octave filters. The system consists of the measuring amplifier type 2606, the octave/third-octave filters types 1614 and 1615, and the frequency analyser type 2113 which is a combination of the type 2606 and the type 1615. The measuring amplifier and the frequency analyser have a sensitivity of  $10\mu\text{V}$  for full deflection. A new rectifier gives correct r.m.s. indication for signals with crest factors up to 40. Two indicators light up if the amplifiers are overloaded and allowable crest factor is exceeded. Interchangeable scales give direct reading of both sound and vibration levels with all B & K accelerometers and condenser microphones. An impulse measuring facility with maximum hold enables impulse sound measurements to be made to the proposed I.E.C. standards. All four weighting networks, A, B, C and D, are built-in. The two new bandpass filter sets, of which the 1615 is included in the analyser type 2113, also have new features. Frequency range for the type 1614 filter is from 2Hz to 160kHz and for the 1615 filter is from 22.4Hz to 22.4kHz. Both filter sets are in accordance with the I.E.C. 225-1966 and the U.S.A.S.I. S1.11-1966 class III filters. This means they have a very flat passband, within  $\pm 0.25\text{dB}$ ; and a very high damping outside the passband, better than 75dB at 5.2 times the centre frequency. The filters below 200Hz are made as active

filters. All filters can be scanned automatically with the B & K level recorder type 2305 for automatic recording of sound-vibration and other spectrograms. B & K Laboratories Ltd, Cross Lances Road, Hounslow, Middx.  
**WW 320 for further details**

### Digital-to-synchro Converter

Analogue servomechanisms using synchros may be controlled from digital computers, or other equipment producing pulses by means of a digital-to-synchro converter introduced by Moore Reed. The device accepts 11-bit binary number pulses, in serial or parallel form, representing the desired angular position of the synchro shaft. It converts each number, in a time of 20 $\mu$ s, to a three-phase synchro signal that is proportional to the digital input and is also related to the reference signal of the analogue servo system (50, 60 or 400Hz sinewave, 26 or 115V r.m.s.). Each binary increment represents approximately 10 $\frac{1}{2}$  minutes of arc in shaft rotation. Digit pulse levels at the input: logic "1" is 5V; logic "0" is 0 to +0.5V.

The converter can be made available as a number of printed circuit cards for wiring into equipment, or as a complete chassis-mounted assembly already wired up and operating. Power supply lines required are +15V and -15V d.c., 1.2A each line. Moore Reed and Company Ltd, Walworth Industrial Estate, Andover, Hants.

**WW 315 for further details**

### Super Megohmmeter

British Physical Laboratories were showing a super megohmmeter, model RM170, covering resistance values of from 500k $\Omega$  to 1000T $\Omega^*$  at 500V test voltage in 17 ranges. It employs an amplifier with m.o.s.-f.e.t. input and several i.cs and is produced in modular construction. Basic resistance range is 100k $\Omega$ -2M $\Omega$  at 100V test voltage with multipliers of  $\times 3$ ,  $\times 10$ ,  $\times 30$ ,  $\times 100$  . . . .  $\times 10^8$ . The RM170 will read currents from 0-10pA to 0-1mA in 17 ranges. Here the basic range is 0-10pA (10<sup>-12</sup>A). Test voltage is 5-500V d.c. and measurement time 100ms (>1nA or <0.5T at 500V) and 5s (<100pA or <5T $\Omega$  at 500V). A special feature is a built-in go/no-go lamp limit indication with an output voltage accessible for driving automated test systems. A selector switch enables earthed or unearthed samples to be measured. The instrument is fully protected against any overload that may occur as a result of use on incorrect range. Operation is from 110-125V or 200-250V 50/60 a.c. mains. Dimensions 330  $\times$  210  $\times$  140mm. British Physical Laboratories, Radlett, Herts.

**WW306 for further details**

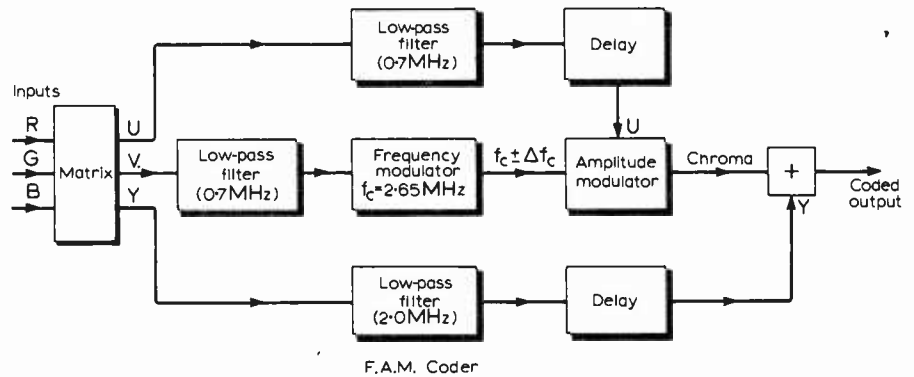
\*Teraohms (10<sup>12</sup>)

### FAM Colour Adaptor

Readers will be familiar with the characteristics of PAL, N.T.S.C. and SECAM colour television systems but may know little of another system called FAM (frequency-amplitude modulation) which was developed by IRT, Munich, and was once a contender for the European broadcast standard. This system, however, has been adopted by Ampex for a colour adaptor developed by the company for use with their 1-in helical scan

applied to an f.m. detector and an a.m. detector recovering the respective *V* and *U* signals. Chrominance information is removed from the *Y* signal by a delay line notch filter with maximum attenuation at 2.65MHz, and the three signals (*Y*, *V* and *U*) are fed to a matrix producing *RCB* outputs. Because of the restricted luminance bandwidth, the loss in picture resolution is compensated by a crispening technique which enhances outline detail.

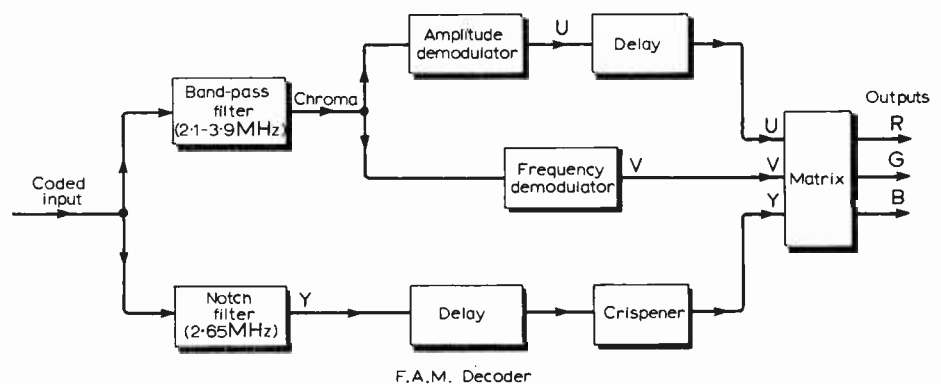
As supplied, the FAM colour adaptor is capable of working on 525/60 or 625/50



videotape recorders. The unit cost about £625 and its chief merit is that it will provide a colour facility on systems which are normally suitable for monochrome transmissions only because of bandwidth restrictions and poor phase response.

*RGB* signals entering the encoder are converted into a luminance signal *Y*, a red difference signal *V* (*R*-*Y*) and blue difference signal *U* (*B*-*Y*). Low-pass filters restrict the bandwidths to 2MHz for the *Y* signal and 0.7MHz for the *U* and *V* signals. The

standards and synchronizing pulses of broadcast or industrial type without the need for switching or adjustment. It will accept *RCB* inputs with or without synchronizing pulses; with non-composite inputs, an external sync input is required. *RGB* outputs are composite only and an external sync output is provided. Unlike established systems, the FAM sub-carrier is not a function of the line frequency so that it is independent of line and field standards. Although the carrier frequency



*V* signal is applied to a frequency modulator (centre frequency 2.65MHz) and the f.m. signal is then amplitude modulated by the *U* signal, and added to the luminance signal. The resulting coded signal occupies a total bandwidth of only 3MHz.

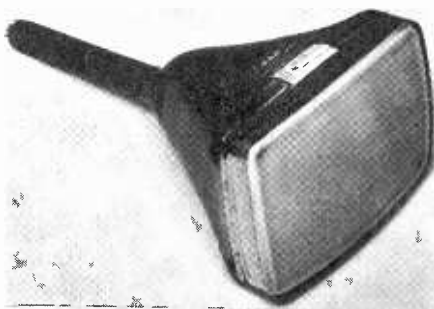
In the decoder no phase-sensitive circuits are required. The chrominance information is separated by a bandpass filter with 6dB points at 2.1 and 3.9MHz and is then

and bandwidth specifications have been chosen for the Ampex 1-in helical scan recorders, these standards can be varied to suit narrower or wider bandwidths, where available. The FAM encoded signal is not monochrome compatible. That is, an FAM recorded tape cannot be played through a black and white monitor. Ampex Great Britain Ltd, Acre Road, Reading, Berks. RG2 0QR.

**WW 301 for further details**

## Bright Display Tube

Included in a new range of c.r.t.s on the M-O Valve stand was model 2800A, a

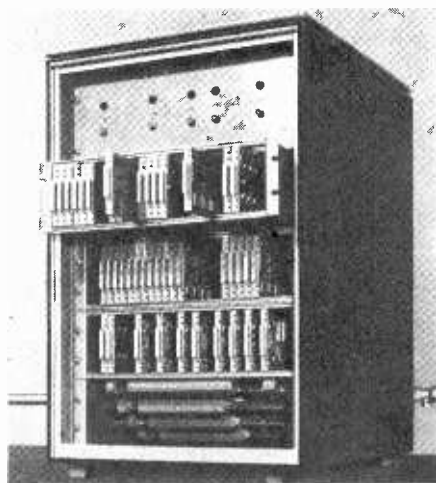


280mm diagonal data display tube operating at 8kV and using P39 phosphor to give a bright display down to 30Hz repetition rate. The manufacturers claim that the electron gun and focusing system design is capable of giving better resolution than conventional c.r.t.s of similar size and brightness. The spot has a sharp edge due to non-gaussian distribution of electrons in the beam and resolution at the edge of the display is improved by a reduced beam diameter. This company was also showing several microwave products including a rugged, pulsed, low inter-line noise tunable X-Band magnetron with a rapid warm-up cathode. This was type E3320 which operates at a very low voltage—typically 8-900V and produces up to 300W peak power. The tuning range is  $\pm 25$ MHz. The M-O Valve Co. Ltd, Brook Green Works, London W.6.

WW310 for further details

## Telemetry System for Process Control

A fully comprehensive telemetry system for industrial data acquisition and remote supervisory control was given its first showing by Kent Instruments. Developed for applications such as petrochemical processing, public utilities and power generation, the telemetry system, designated Dataflex, is claimed to offer

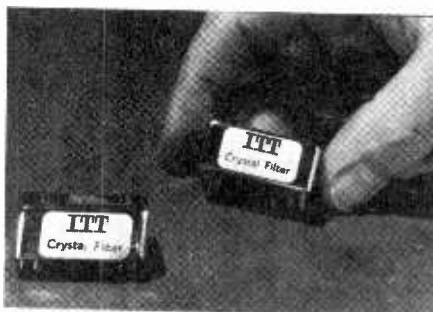


economy and flexibility through the use of modern modular components. It is compatible with all modern process control instrumentation and with Kent's K70 computer system. Described as a digital time-division multiplex system, Dataflex incorporates remote control, supervision and monitoring of physical variables between a central control position and up to 64 separate outstations. Each outstation will be basically identical having seven plug-in circuit boards and wired to take additional modules as required. The master station has similar plug-in modules. Information, event signals and commands can be transmitted over Post Office or private lines and u.h.f. radio links. The speed of the system can be 100, 200, 600, 1200 or 4800 bauds through data transmission modems or by direct injection into the transmission line via line drivers. Kent Instruments Ltd, Biscot Road, Luton, Beds.

WW 308 for further details

## Monolithic Crystal Filters

Monolithic crystal filters with channel spacings of 50, 25, 20 and 12.5kHz available from ITT Components Group Europe at Harlow, offer 90dB stop-band discrimination. The common input and output impedance for all channel spacings is  $910\Omega$  in parallel with 25pF. The standard case sizes are 901 and 923.



The 923 case may be ordered with isolated earth or non-isolated earth as desired. ITT Components Group Europe, Quartz Crystal Product Division, Edinburgh Way, Harlow, Essex.

WW 317 for further details

## Tunable Gunn-effect Oscillators

A Gunn-effect oscillator with an output power greater than 5mW and capable of being electronically tuned from 7 to 12.4GHz was shown by Microwave and Electronic Systems. The tuning is achieved by means of an yttrium-iron-garnet sphere magnetically biased to resonance, in which condition it is electrically equivalent to a shunt resonant circuit. There is an isolator on the output of the oscillator, allowing the oscillator to "look at" open- or short-circuited loads



without deterioration in performance. Other similar tunable oscillators available from the company have tuning ranges of 4-8GHz and 12-18GHz. Microwave and Electronic Systems Ltd, 66 Tilehurst Road, Reading, Berks. RG3 2LU.

WW 316 for further details

## Industrial Semiconductors

New semiconductor devices exhibited by Mullard included four f.e.t.s intended for switching applications and three dual-in-line packages containing four discrete transistors. Three of the f.e.t.s, types BSV78-80, are n-channel devices that are electrically symmetrical and have very low "on" resistance and extremely high "off" resistance. Maximum drain-to-source voltage is 40V. The fourth, type BSV81, is a depletion-type, insulated-gate device in a metal envelope with the substrate connected internally to the case. Because of its very high "off" resistance ( $> 10G\Omega$ ) it is particularly suitable in applications where extremely low leakage currents are important during the "off" periods. The three new multiple solid-state devices on display contained four transistors of the same type, matched for gain, within a 14-lead d.i.l. encapsulation. This facilitates the layout of printed boards designed for use with i.c.s. The transistors are not interconnected and can be used as discrete components. The three devices are development types 272BC7, 273BSX and 274BC7. They contain four BC107, four BSX 19 and four BC177 transistors respectively.

Among piezoelectric material exhibited was a sonic detector type MB4013 which is intended for use in remote control systems operated by sound waves. It has a resonant frequency of  $6kHz \pm 0.4kHz$  and a 3dB bandwidth of 80Hz (independent of load). Impedance is  $7k\Omega$  and capacitance at 100kHz  $> 4,300pF$ . The MB4013 consists of a disc of PXE5 material mounted centrally on an aluminium diaphragm held by a zinc ring. Because, unlike other forms of sound detector, the

response is limited to a narrow frequency band, no extra stages are required to filter out signals at unwanted frequencies. The sonic detector is unaffected by moisture, large temperature changes or adjacent magnetic fields. Mullard Ltd, Mullard House, Torrington Place, London W.C.1. **WW309 for further details**

## Power Supplies

Coutant showed two new ranges of power supplies. The GP series of regulated a.c.-d.c. power supplies, comprises a total of 15 units. Within the range, models are available with fixed outputs of 6, 12, 18 or 24V. This series includes various models with current ratings of 2 to 10A in the 6V range and 1 to 10A in the other three voltage ranges; its three physical sizes (which depend on the rating required) are all based on BS 4318 metric preference dimensions. Other principal specifications for the GP series are a



line regulation of 0.01%+1mV; load regulation of 0.03%+3mV (0 to full load); 1.5mV ripple voltage; re-entrant protection; input a.c. voltages of 220 or 240V a.c.  $\pm 10\%$ , with a frequency range of 45 to 400Hz; a temperature coefficient of 0.02%+2mV per  $^{\circ}\text{C}$ ; and nominal d.c. outputs variable  $\pm 10\%$ .

Coutant's other new power supply range—the BPS—is an unregulated series offering four voltage ranges (6, 12, 24 and 48V) at 2, 5 and 10A. Like the GPs, they are available in sizes based on BS 4318, and will operate from an a.c. mains input of 220 or 240V  $\pm 10\%$ ; regulation is 20% for a 10 to 100% load variation; ripple is 2V r.m.s., and the ambient operating temperature range is 0 to 55 $^{\circ}\text{C}$ . Coutant Electronics Ltd, 3 Trafford Road, Reading RG1 8JR. **WW 321 for further details**

## Digital Voltmeter

From Bradley, a small size high performance digital voltmeter, type 173, will measure from 100 $\mu\text{V}$  to 1000V d.c. in four ranges. An additional  $\times 4$  range reads down to 25 $\mu\text{V}$ , whilst the provision of a 50% over-range facility extends the



maximum reading to 1500V. Common mode rejection is typically 140dB at line frequency. The accuracy is  $\pm 0.01\%$  of reading  $\pm 1$  digit and the instrument is calibrated by using an unsaturated standard cell as an internal reference. Automatic indication of polarity is incorporated as standard, and display storage is provided to eliminate flicker. 1-2-4-8 coded data output is available at the rear panel. The price complete is £340. G & E Bradley Ltd, Electrical House, Neasden Lane, London N.W.10. **WW 318 for further details**

## Calibration Sound Source

A pocket-size instrument which produces a standard sound level for calibrating sound level measuring instruments has been introduced in the U.K. by B & K Laboratories. Made by Brüel & Kjaer (Denmark), it generates a sound level of 94dB (this being a dynamic pressure of 1N/m $^2$  in SI units) at a frequency of 1kHz. The calibrator uses a piezo-electric transducer driving a diaphragm which creates the standard pressure level in a coupler chamber. Behind the diaphragm is a Helmholtz resonator which gives the system an equivalent coupler volume of more than 200cm $^3$  at its resonant frequency. Driving the system at this frequency therefore results in low distortion and makes the generated sound pressure independent of both the static pressure and the equivalent volume of the microphone to be calibrated. B & K Laboratories Ltd, Cross Lances Road, Hounslow, Middx.

**WW 314 for further details**

## Distortion Factor Meter

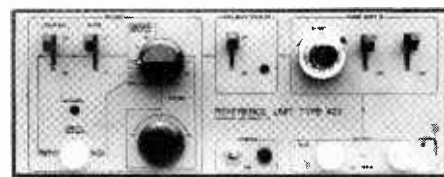
Distortion factor meter type DM344 by Sign Electronics Ltd, was being shown on the Aveley Electric stand. This is an instrument comprising two basic sections, a filter and a voltmeter, designed to measure total harmonic distortion in high quality audio amplifiers, recording and transmission equipment. The filter is used to remove the fundamental component of the signal and the voltmeter to measure

the residual harmonic components, and to establish the initial reference level. Frequency range is 20Hz-20kHz for fundamental in six third-decade bands. Fundamental attenuation is  $> 80\text{dB}$  and second harmonic  $< 0.5\text{dB}$ . The harmonic bandwidth is 100kHz. The instrument residual distortion is  $< 0.1\%$  from 10Hz to 10kHz. Input impedance is 10k $\Omega$ /V or 600 $\Omega$ , overload protected to 100V. Aveley Electric Ltd, South Ockendon, Essex.

**WW 302 for further details**

## Reference Unit for Lock-in Amplifiers

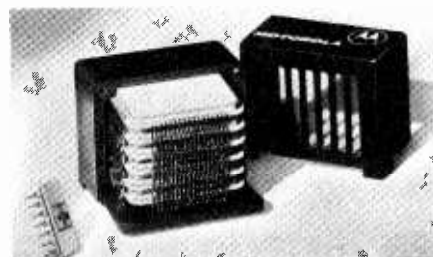
Lock-in amplifiers, which are signal-recovery devices working on the synchronous detector principle, require a local reference source of oscillation which can be adjusted in frequency and phase. Brookdeal Electronics have produced an instrument called Reference Unit Type 422 which takes an input signal of any wave-shape (frequency range 1Hz to 1MHz), uses it to generate a square-wave output (+3V from 100 $\Omega$  impedance) and provides means for adjusting the phase of this output signal,



relative to the input signal, in various ways. For example, there are two outputs available, one 90 $^{\circ}$  phase-advanced on the other. Control of phase can be: 0 to 100 $^{\circ}$  variable; 0 or 90 $^{\circ}$  switched; 0 or 180 $^{\circ}$  switched. In addition phase shift may be controlled by an external programming voltage: +1V to -1V gives +90 $^{\circ}$  to -90 $^{\circ}$ . The input level range is 10mV to 100V (pk) and the input impedance is greater than 10k $\Omega$ . Brookdeal Electronics Ltd, 1 Market Street, Bracknell, Berks. **WW 313 for further details**

## Semiconductor Random-access Memory

Full semiconductor memories for computers are possible utilizing a new device launched by Motorola. This was a mono-



lithic high-speed random access memory with an 8192-bit capacity. Constructed with l.s.i. techniques, the module combines the low power of p-channel m.o.s. flip-flops for the storage array with the high operating speed of bipolar transistors for the address decoding, word drive sense and digit drive circuits. No complicated tuning is necessary to operate the module which can be cycled every 100ns. Interface to and from other circuitry is performed at emitter-coupled logic current levels for high speed. It can be easily interfaced to saturated-logic levels with the use of additional interface devices. Motorola Semiconductors Ltd, York House, Empire Way, Wembley, Middx.

WW 311 for further details

## Transducer Read-out Unit

Designed primarily for use with their T500 series pressure transducers, Southern Instruments introduced a readout unit type M1861. This displays an output voltage on a panel meter which varies

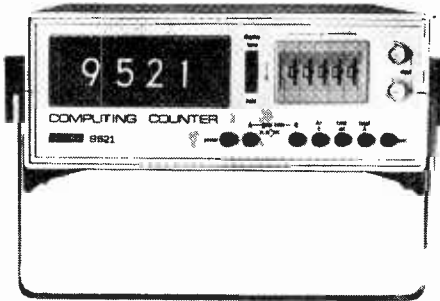


proportionally to input pressure. The meter can be scaled directly in pressure units and the unit sensitivity can be set to suit any transducer without the need for system calibration. A crystal-controlled reference frequency gives good zero stability and an adjustable reference voltage is provided. Zero drift is less than 0.03% f.s.d./°C. Other characteristics include: linearity  $\pm 1\%$ , noise level less than 25mV p-p at output, frequency response better than 0-500Hz (-3dB). Voltage output is 0-10V, output resistance  $< 1\Omega$ . A connection is provided to allow marker pulses to be added into the amplifier output. U.K. price of model 1861 is £96. It measures 200 x 290 x 102mm and weighs 1.6kg. Operation can be from 100/125 or 200/250V, 50-65Hz mains supplies. Southern Instruments Ltd, Frimley Road, Camberley, Surrey.

WW 307 for further details

## Computing Counter

One of a new series of digital instruments shown by Racal was a computing counter, model 9521. Of half-rack-width dimensions and incorporating t.t.l. integrated circuits, it has a timebase variable in 100- $\mu$ s steps from 100 $\mu$ s to 10s. This facilitates direct indication of speed, ratio, time interval etc, on the four-digit display. The com-



puting counter is expected to find wide application in the process control industry where it can provide accurate indication of gallons per minute, r.p.m. or similar parameters. Capabilities include frequency measurement (5Hz-10MHz) on either of two channels, frequency ratio, time interval and totalize. Racal Instruments Ltd, Duke Street, Windsor, Berks.

WW 303 for further information

## Modular System for Counting, Storing and Display

For designers of control consoles and panels who need a "building block" system which will relieve them of logic design responsibility, and which does not require rack-mounted hardware, Contraves were showing the Codicount system. This provides ten variations in a module 22mm wide x 33mm high, dimensionally compatible with the new Multiswitch which is used for preselection of constants such as factors and datum levels. Codicount modules employ i.cs, ensuring short transmission lines. Good frequency response, high reliability and freedom from noise problems is claimed. The logic supply terminal, on each module, is decoupled from line noise by a tantalum capacitor. The circuit components will operate at frequencies well in excess of the module rating of 5MHz giving an assured safety margin. Function permutations vary from read-out display with decimal input, to bi-directional counter with memory and read-out, or without read-out. Supply voltages required are +5V for the logic system at 21-105mA depending on the module type, and +250V at 2.2mA for the read-out tube. The Multiswitch, which is compatible dimensionally with the Codicount, is based on five new types in the existing miniature range. Innovations include improved readability and an enclosure for logic components. Contraves Industrial Products Ltd, Times House, Station Approach, Ruislip, Middx.

WW322 for further details



## Variable Filter

A new solid-state variable filter instrument, model EF2, was shown by Barr & Stroud. This contains two independent low- and high-pass filter channels and it has a frequency range of 0.1Hz-100kHz in five decades. Attenuation slope can be 36 or 72dB/octave and maximum attenuation 75dB. Bandpass, band stop or band separation functions are selected by switch. Operation is from an integral power supply or external batteries and the output is short-circuit protected. Barr & Stroud Ltd, Caxton Street, Anniesland, Glasgow W.3.

WW 312 for further details

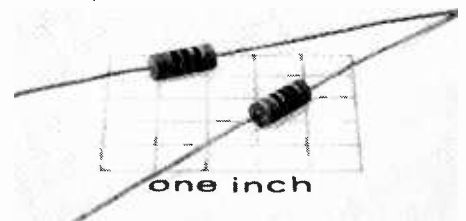
## Micro-miniature Potentiometers

Among several new types of potentiometer introduced at the Show by Painton was the 3260 which is only 6.35mm square and has a power rating of 0.2W at 70°C. It is available in a range of eleven values from 10 $\Omega$  to 20k $\Omega$ , and in two configurations—for side adjustment and top adjustment. Nominal resolution of a 100 $\Omega$  potentiometer is 0.82% and of a 5k $\Omega$  device 0.30%. Painton & Co. Ltd., Kingsthorpe, Northampton.

WW324 for further details

## Sub-miniature Choke

A sub-miniature choke, type 550-3399, from Cambion is only 0.25in long x 0.095in in diameter, but offers a continuous range of inductance values from 0.1 to 1000 $\mu$ H in 49 discrete steps. Cambion



Electronic Products Ltd., Cambion Works, Castleton, Near Sheffield.

WW 319 for further details



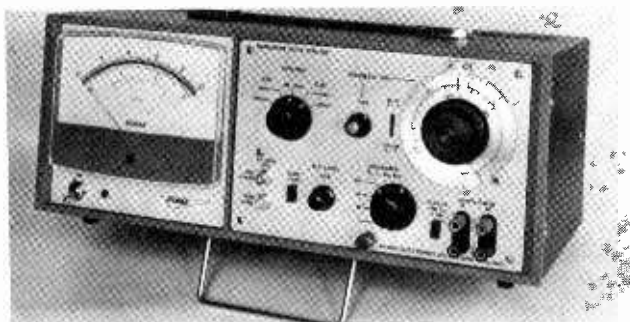
### Carrier Servo Generator

Newcomers to the I.E.A. exhibition, Prosser Scientific Instruments used the occasion to announce their A103 carrier servo generator. This instrument is based on the previous A100 waveform generator and is intended for a.c. and d.c. servo and system measurements. It provides a two-phase carrier modulated output and is available with either manual or automatic control of phase and frequency. The instrument can also be used as a multiple output function generator for sine, square, ramp and triangle waveforms. Frequency range is 0.0008Hz to 200kHz and output voltage  $\pm 10V$  peak (maximum). The attenuator has a switched range of 0-10, 20, 30 . . . 60dB with fine control between 20-100% of switched amplitude. Phase is  $+280$  to  $-100^\circ$  on variable phase output,  $+90^\circ$  on auxiliary output and  $0^\circ$  on main output. Cost of the A103 is £615. It is illustrated at the top of the page. Prosser Scientific Instruments Ltd, Lady Lane Industrial Estate, Hadleigh, Ipswich, Suffolk.

WW326 for further details

### Portable A.F. Power Meter

Dymar were showing their new portable a.f. power meter type 585. This comprises the basic meter unit, common to all Dymar instruments, and a plug-in circuit module. A wide power-measuring range is provided in the frequency range 30Hz-30kHz. High accuracy of the terminating impedance and measured power is claimed. Twelve power ranges in 1, 3, 10 sequence give f.s.d. readings from  $100\mu W$  to 30W and an auxiliary scale allows direct readings in dBm ( $0dBm = 1mW$ ) from  $-20$  to  $+45dBm$ . A temperature-compensated "square law" detector gives a true power reading irrespective of waveform, particularly



useful for accurate measurement of noise. There is a choice of 30 input impedances arranged in 3 decades from  $1.25\Omega$  to  $1,000\Omega$  each capable of dissipating 50W with an accuracy of 2%. The 585 is battery-operated and weighs 6kg. An illustration of the Dymar common meter unit, fitted in this case with modulation meter type 765, appears at the foot of the page, left. Dymar Electronics Ltd, Colonial Way, Radlett Road, Watford, Herts.

WW325 for further details

### Digital Multimeter

Solartron are aiming at the mass market for the first time with a digital multimeter,



type LM1240. The new instrument has 26 ranges and is capable of measuring a.c. and d.c. voltage and current, and resistance. It is priced at £195 and is claimed to incorporate features regarded as standard in high-priced d.v.m.s. These include automatic polarity, high input resistance, an integration technique to

eliminate noise, fully isolated input, overload protection and the option of mains or battery operation. By comparison with the traditional analogue meter the LM1240 offers improved accuracy, ease of reading both polarities, and input resistance defined in megohms rather than ohms per volt. The Solartron Electronic Group Ltd, Farnborough, Hants.

WW305 for further details

### Economy S.C.R.

A low-cost s.c.r. designed for use in consumer electronics was shown by Transiron. This is a 4-A type, housed in four alternative plastics flat packs, available in the voltage range 15-400V. Peak forward current of 75A at  $75^\circ C$  is featured. It is designated TC106. Transiron Electronic Ltd, Gardner Road, Maidenhead, Berks.

WW323 for further details

### Wide-range Oscillators

A series of oscillators, TG200 series, that cover 1Hz to 1MHz in twelve ranges were introduced by Levell Electronics. Versions are available that generate sine and square waves or sine waves only. Output is variable from  $200\mu V$  to 7V r.m.s. by a variable control and switched attenuator with 10dB steps up to 70dB. Output impedance is  $600\Omega$  at all settings. The circuit uses a single-track linear potentiometer giving frequency control with absence of amplitude bounce, characteristic of Wien bridge circuit with dual-track controls. Amplitude variation is less than  $\pm 1\%$  up to 300kHz. Rise time on square waves is less than 150ns at all frequencies. Harmonic content on sine waves is less than 0.1% up to 5V output from 10Hz to 100kHz. Power supply can be from four PP9 batteries or a.c. mains if power unit is fitted. Dimensions of the TG200 are  $180 \times 250 \times 140mm$ , and weight 4.5kg. It is illustrated below. Levell Electronics Ltd, Park Road, High Barnet, Herts.

WW304 for further details





# World of Amateur Radio

## Pressure on v.h.f./u.h.f. bands

Further evidence of the mounting pressure being applied by mobile radio interests in efforts to take over amateur sections of the v.h.f. and u.h.f. bands is provided in the recently published annual report (1969) of the Electronic Engineering Association. The section reporting the current activities of the E.E.A. Radio Communications Division contains the following passage: "The lack of spectrum space continues to be seen as the most likely factor which could seriously limit the expansion of mobile radio communications. Negotiations have therefore now begun with the Ministry of Posts and Telecommunications to secure use of the 68 to 71.5 MHz and 420 to 450 MHz bands."

While most amateurs appreciate the increasing demands being made to secure maximum use of all frequencies in this part of the radio spectrum, most will note with considerable concern and regret that the E.E.A. claim includes the entire amateur 4-metre and 70-cm bands (currently 70.025 to 70.7 MHz, and 425 to 450 MHz with a gap from 429 to 432 MHz). Amateurs may thus regard this claim in the nature of a test case in which the outcome may well indicate the future intentions of Minpostel towards amateur frequency allocations. Some may suspect, however, that by putting in claims of this magnitude, the mobile radio industry is aiming primarily at the upper portion of the 70-cm band, with many amateurs seeing the section 440 to 450 MHz at particular risk.

## Old timers

Among the many associations and groups of radio amateurs having local or special interests, a few have come to occupy a highly respected role. Undoubtedly one of these is the Radio Amateur Old Timers' Association which was formed some 17 years ago.

The object of R.A.O.T.A. is to maintain and foster a spirit of friendship among amateur transmitters of long standing, and to be mindful of any who may be in special need. Membership is open to all transmitting amateurs who were licensed, with either a radiating or artificial aerial licence, before September 1939, and

who currently hold a British transmitting licence. Membership is limited to 300; at present it is about 50 below this figure. The membership fee is £1 1s. Applications may be sent to the honorary secretary, Miss May Gadsden, 79 New River Crescent, London N.13.

President of R.A.O.T.A. is Kenneth Alford, G2DX, whose amateur radio activities stretch back to the pre-World War I era; a 1914 issue of *Wireless World* described the four-wire cage aerial, high-speed mercury turbine "break", his nine Leyden jars and the three "jiggers" with which he could work distances of over 10 miles.

## On the h.f. bands

Despite the falling off of maximum usable frequencies due to the approach of summer conditions, plenty of West Coast American, Canadian and Mexican stations have been coming through in the early mornings at good strength and can be worked with simple vertical and dipole aeriels. Recent contacts, for example, have been with VU5XX Andaman Islands, 7Q7AA Malawi, UAoYT and JTIAH both in the usually rare Zone 23, SM6CNS maritime mobile in the Mozambique Channel and similarly SM5CTU/MM a Swedish ship off the west coast of Central America. Among the rarer calls heard on 14 MHz c.w. have been DU1OR near Manila, YA2HWI/1 Kabul, Afghanistan, UA1KED Franz Josef Land, and PJ2PS near Curacao. King Hussein, who operates on 28 MHz phone from Amman with the callsign JY1 is known to have worked British amateurs recently. The Thor Heyendahl expedition on the raft *Ra II* is again using the callsign LI2B (s.s.b. on 14214 kHz).

## V.H.F. activities

For the first time, a two-way link has been established on 144 MHz between the U.K. and Iceland. John Stace, G3CCH, of Scunthorpe, Lincolnshire, made contact, via meteor scatter, with Finar Palsson, TF3EA, over a distance of about 1100 miles, during the Aquarids meteor shower in early May. Another widespread auroral opening occurred both in Europe and North America on April 21st-22nd. The

70-cm beacon station, GB3SC, is now operating with aeriels mounted 300 ft up the B.B.C. Sutton Coldfield mast. One aerial beams north, another towards the south-south-east. The station uses frequency shift keying on 433.5 MHz to a 24-hour schedule. The Rhodesian beacon station, ZE2AZE, is similarly running continuously on 69.998 MHz from a site over 4000 ft above sea level, with just over 20-watts input to a four-element Yagi.

## World DX Club conference

The annual conference of the World DX Club takes place over the weekend July 3rd to 5th at the Adelphi Hotel, Micklegate, Yorkshire. During this period the conference station GB2WDX will be in operation. Although this is primarily a club for broadcast-band short-wave listeners, it includes an active amateur radio section.

**In Brief:** Licences figures to the end of March show that in five months, Class B licences have risen by 187 to 2084 compared with an increase of 73 in Class A licences to 13486. With one additional amateur TV licence (180), U.K. amateur licences (excluding mobile permits) totalled 15,750 . . . Derby and District Amateur Radio Society is holding a mobile rally on August 16th at Rykneld School, Bedford Street, Derby (details T. Darn, G3FGY, "Sandham Lodge", Sandham Lane, Ripley, Derby) . . . The A.R.M.S. mobile rally, announced for July 5th at Alconbury, has been cancelled . . . The Stourbridge society, in collaboration with the management of the narrow-gauge Welshpool and Llanfair railway are setting up, on July 4th, an amateur station, GW6OI/P, at the Llanfair Caereinion terminal; this will operate during the afternoon mainly on 3.5 MHz . . . GB3WRA will be set up again this year at the 24th annual High Wycombe show on the Rye on September 5th, operating in all bands from 1.8 to 28 MHz (details A. C. Butcher, G3FSN, 70, Hughenden Avenue, High Wycombe, Bucks.) . . . When Senator Barry Goldwater, K7UGA, visited Vietnam he left behind slow-scan TV equipment which has been used from Cam Ranh Bay on the U.S. military-affiliate radio system frequency of 19.2 MHz to transmit pictures back to Senator Goldwater's MARS station AF7UGA in Phoenix . . . George Grammer, W1DF, who joined A.R.R.L. staff in 1929 and has been technical editor of *QST* since 1939, has recently retired. Doug De Maw, W1CER/W8HHS, has been appointed acting technical editor. He has strong "family connections" with amateur radio, apart from his own two callsigns his wife is W1CKK and his son WN1LZQ . . . Contests for home-constructed equipment will again be a feature of the R.S.G.B. Show which this year is being held from August 19th to 22nd, in the New Horticultural Hall, London.

PAT HAWKER, G3VA

# Literature Received

*For further information on any item include the WW number on the reader reply card*

## ACTIVE DEVICES

"Designers Guide" gives pin connections and loading rules for the series 54/74 t.t.l. integrated circuits produced by Transistron Electronic Ltd, Gardner Rd, Maidenhead ..... WW401  
Price list for above range ..... WW402

The 54/74 range of t.t.l. is also the subject of a 29-page catalogue from Fairchild Semiconductor Ltd, Kingmaker House, Station Rd, New Barnet, Herts. Performance data and other relevant details are given ..... WW403  
Price list for above range. .... WW404

"Integrated Circuits t.t.l. series (TL . . . 74N)" is a 119-page booklet giving pin connections, loading rules, performance data, and application information on the 74 series t.t.l. integrated circuits available from AEG-Telefunken, Fachbereich Halbleiter Vertrieb, 71 Heilbronn, Postfach 1042, West Germany ..... WW405

The 1970 edition of the ever popular "Mullard Data Book" is available. It lists valves, semiconductors, television tubes and other components. The price is 4s to individuals outside the radio and television trade. It may be obtained from bookshops and component dealers.

We have received a batch of data sheets from Brimar, Thorn Radio Valves and Tubes Ltd, 7 Soho Square, London, W1V 6DN.

D14-170GH, 10 × 8cm oscilloscope tube. .... WW406  
"GV Screen for Data Display and Radar". Very long persistence phosphor. .... WW407  
D14-180GH, 10 × 8cm oscilloscope tube. .... WW408  
"Monoscopes". Character generating tubes—gives some application information. . . . WW409  
M38-100GH, -100W, -101GH, -111GH, 38cm data display/monitor tubes. .... WW410  
D13-600GH, 13.3cm oscilloscope tube. WW411

An equivalents chart for Vidicon camera tubes is available from E.M.I. Electronics Ltd, Hayes, Middlesex ..... WW412

The range of potted amplifiers produced by Ancom Ltd, Devonshire St, Cheltenham, GL50 3LT, are the subject of a leaflet; all the significant characteristics are given ..... WW413

"Application Report No. 5" from Brookdeal Electronics Ltd, Market St, Bracknell, Berks, deals with the automatic measurement of semiconductor junction capacitance ..... WW414

"Data Distribution No. 6" contains a number of leaflets for insertion in the Ferranti Microspot Cathode Ray Tubes and Display Equipment Manual. Ferranti Ltd, Gem Mill, Chadderton, Oldham, Lancs ..... WW415

"Issue 15" from AEI Semiconductors, Carholme Rd, Lincoln. contains data sheets for inclusion in the AEI Semiconductors Technical Data Handbook. .... WW416

We have received the following literature from Westinghouse Brake and Signal Co. Ltd., 82 York Way, Kings Cross, London N.1.

Engineering publication D/WB "Silicon Diodes". Low, medium and high power. .... WW417  
Technical publication T17. "Thyristor type 17TX, 16A". .... WW418  
Technical publication T20. "Thyristor type 20TX, 20A". .... WW419  
Technical publication 36-113. "Power transistor type 2N3054". .... WW420  
Technical publication 36-114. "Power transistors, type 2N3371-3". .... WW421

## PASSIVE COMPONENTS

Termiswitches are rail mounted terminal units which incorporate a relay—they are described in a leaflet from Lion Systems Developments (Gerrards Cross) Ltd, 45/47 Station Rd, Gerrards Cross, Bucks ..... WW422

A catalogue from Fairchild Controls, 225 Park Ave, Hicksville, L.I., New York 11802, U.S.A., describes a range of trimming potentiometers ..... WW423

"Siemens Electronic Components Bulletin, 2-70" contains articles on the demagnetization of colour tubes using p.t.c. resistors, pulse transformers, a surge voltage protector, miniature switches, low-speed logic etc. It is available from Cole Electronics Ltd, Lansdowne Rd, Croydon CR9 2HB ..... WW424

We have received the following literature from Erie Electronics Ltd, South Denes, Great Yarmouth, Norfolk, which is intended for inclusion in the Erie catalogue:

PCF/5, metallized film capacitors, polycarbonate series PE31A. .... WW425  
PCF/4, metallized film capacitors, "Metalmac" series ML30A. .... WW426  
EC/6, aluminium electrolytic capacitors, 201 series. .... WW427

Mullard have produced a wall chart (36 × 26 inches) dealing with their electrolytic, film and variable capacitors. Copies of the chart can be obtained from A. Stewart, I.E.D., Mullard Ltd, Torrington Place, London, WC1E 7HD ..... WW428

A triple-sheet wall chart (20 × 22 inches) has been prepared by Ultra Electronics (Components) Ltd, Fassetts Rd, Loudwater, Bucks. From this it is possible to select a variety of wafer switches. WW429

## EQUIPMENT

An interesting self-powered tachometer system (0 to 500, 1,000, 2,000, 5,000, 10,000 or 20,000 r.p.m.) requiring no mechanical link to the shaft being monitored is described in a leaflet from the Dynalco Corporation, 4107 N.E. 6th Avenue, Ft Lauderdale, Florida 33308, U.S.A. .... WW430

A four-terminal resistance bridge (type K.B.5) is the subject of a leaflet from the Croydon Precision Instrument Company, Hampton Rd, Croydon, CR9 2RU. It covers 0 to 111, 110 Ω with five decade dials and incorporates eight switch-selected standard resistors ..... WW431

A capacitor-discharge ignition system is described in a leaflet obtainable from Argent Electronics

Company, 805 Kam Chung Building, 54 Jaffe Rd, Hong Kong. .... WW432  
Nuclear Enterprises Ltd, Bath Rd, Beenham, Reading, have prepared a 129-page catalogue which lists a huge range of electronic and scientific test and measuring apparatus ..... WW433

A decade resistance box, amplifiers, various oscillators and other measuring equipment are described in the catalogue of Levell Electronics Ltd, Park Rd, High Barnet, Herts ..... WW434

A 47-page catalogue devoted entirely to power supplies is available from Lambda Electronics, Marshlands Rd, Farlington, Portsmouth PO6 1ST .... WW435

We have received the following leaflets from Sivers Lab, Old Haverhill Rd, Little Wratting, Suffolk.

PM7512, Coaxial video detectors, 2-18GHz. .... WW436  
PM7550, Coaxial switches d.c. -18GHz. .... WW437  
PM7101X, Rotary vane attenuator, 0-60dB, 8.2-12.4GHz. .... WW438

The following data sheets dealing with lasers have been received from Ferranti Ltd, Dunsinane Ave, Dundee, Scotland.

DDF/501/370. Argon Laser Type 200 ..... WW447  
DDF/502/370. High-power CO<sub>2</sub> laser ..... WW448  
DDF/503/370. CO<sub>2</sub> laser powermeter ..... WW449

## HARDWARE

"Helpful Hints on Threaded Fastenings" is the title of a 52-page booklet which is produced by Firth Cleveland Fastenings Ltd. It sets out the basic engineering facts and figures that determine the best choice of fastener type, grade and size for a particular application ..... WW439

"Southern's Tool Catalogue", complete with price list, lists a wide variety of tools for electronic and other purposes. Southern Watch and Clock Supplies Ltd, Industrial Tool Division, Precista House, 48-56 High St, Orpington, Kent, BR6 0JH ..... WW440  
Cabinets for housing printed circuit cards are described in a revised catalogue from the Elco Corporation, Willow Grove, Pennsylvania, 19090, U.S.A. It lists 32 standard models which are made in aluminium ..... WW444

A booklet called "PTFE/polyester glass fibre insulators for power transmission" is available from I.C.I., Plastics Division, P.O. Box No. 6, Bessemer Rd, Welwyn Garden City, Herts ..... WW445

Also from I.C.I. a booklet called "Better cleaning the I.C.I. way" which discusses industrial cleaning products and solvents. I.C.I. Mond Division, Thames House North, Millbank, London S.W.1 ..... WW446

## GENERAL INFORMATION

The following information is available from the International Telecommunication Union, Place des Nations, Geneva, Switzerland.

Wall chart describing the organization of the Union and the Consultative Committees. WW441  
Eighth report by the International Telecommunication Union of telecommunications and the peaceful uses of outer space ..... WW442

If you are interested in the performance of nickel/cadmium batteries a new technical bulletin published by the Marketing Services dept, Power Sources Division, Alkaline Batteries Ltd (P.O. Box No. 4, Redditch, Worcs) will be of value. It deals with sealed cells of the sintered plate cylindrical type ..... WW443

The latest book in the "Circuit Concepts series" from Tektronix U.K. Ltd, Beaverton House, P.O. Box 69, Harpenden, Herts, is called "Sampling Oscilloscope Circuits". The price is 10s per copy including postage.

B.S.1568, Part 1:1970, "Specification for Magnetic Tape Recording Equipment" may be obtained from the British Standards Institution, 2 Park St, London W.1. .... Price 14s each

# Personalities

**Stuart Sansom**, M.I.E.R.E., chief engineer of Thames Television (formerly ABC Television) since 1966, has become technical controller. He will be responsible for all technical and engineering facilities of the company (which provides the weekday programmes for the London I.T.A. station) at Teddington, Hanworth & Euston studios. Mr. Sansom, who is 40, spent two years with the Royal Corps of Signals and then joined E.M.I. to continue his technical training, moving to High Definition Films in 1953. Four years later he joined T.W.W., the South Wales I.T.A. programme company, as a vision engineer, afterwards taking charge of electronic maintenance. He joined ABC Television Ltd, as head of engineering equipment group in 1959.

**J. C. Akerman**, head of Mullard's Consumer Electronics Division, has been appointed a director of the company. Mr. Akerman, who is 52, joined Mullard in 1936. After six years' wartime service with the R.A.F. he was made assistant sales manager of the company's Radio Sales Department. He transferred to the Setmaker Department in 1950 and was appointed product manager for cathode-ray tubes three years later. In 1966 he moved to the Industrial Electronics Division as commercial product manager for semiconductor components and



J. C. Akerman

subsequently became a director of Associated Semiconductor Manufacturers Ltd—the company responsible for the development and production of Mullard semiconductor devices. He was appointed to his present post in 1969. He is vice-chairman of the British Radio Valve Manufacturers' Association.

**G. H. Sturge**, M.I.E.R.E., who joined the B.B.C. in 1962, has been appointed assistant head of the Engineering Information Department in succession to **H. T. Greatorex**, B.Sc.(Eng.), who has retired. Mr. Sturge trained as an electrical engineer at Faraday House and from 1946 to 1962 held posts in the service, export and distribution departments of Murphy Radio Ltd. He joined the B.B.C. as an assistant to the Engineering Recruitment Officer and since 1967 he has been head of the engineering section of the Grading Department, with responsibility for the application of job evaluation to technical staff. Mr. Greatorex, who is retiring after 37 years' service, graduated at the City and Guilds College, London, and joined the B.B.C. as an assistant maintenance engineer. In 1935 he went into what is now the Engineering Information Department, of which he has been assistant head for the last 16 years. During this time his responsibilities have included the organization and management of the B.B.C. technical enquiry stands at exhibitions and conferences.

**Brian Shone**, head of the systems development unit in the B.B.C.'s Transmitter Planning and Installation Department has received the Royal Television Society's Geoffrey Parr award for his pioneering work in the design and development of a four-channel combining unit. This system has made it technically possible to use common transmitting aerials for high- and low-power u.h.f. stations.

**Stephen Cox**, a post-graduate research assistant in the depart-

ment of electrical and electronic engineering at Plymouth Polytechnic, has won the 1970 Baird Travelling Scholarship of the Royal Television Society. The award, valued at £500 and financed by Radio Rentals, will be used by him to visit North America in order to gain experience in the theory and practice of educational television production. Mr. Cox is studying the relation of colour to learning in education TV and hopes to present his Doctoral Thesis at Exeter University in 1972/1973.

**Denzil Bradbury** has joined Brookdeal Electronics Ltd as senior designer at their factory in Market Street, Bracknell. Mr. Bradbury joined Hirst Electronic Developments as an improver in 1946 and, after National Service,



Denzil Bradbury

was with Sperry Gyroscope from 1950-1960. Since then he has undertaken contract work as a design engineer, including projects for Decca Electronics, Nuclear Enterprises and Taylor Electronics.

Decca Radio & Television Ltd have announced two appointments in the audio field. **P. B. Cooper**, who is appointed commercial manager (audio) has been associated with Decca for over 20 years and has latterly been manager of special products. He will retain responsibility for this Division in his new post while at the same time extending his sphere of activity to cover all audio products: radio receivers, radiograms, test apparatus and the Deccasound audio systems. **Peter Earthy**, who joined the company in 1965, has become audio development manager.

**Charles Dain** has joined the Electron Tube and Microelectronics Division of EMI Electronics Ltd as facilities director. He will be responsible for all production facilities throughout the Division

and for the manufacture of all established product lines. This will include responsibility for factories, and product operations including camera-tubes and c.r.t.s, non-scanning photoelectric devices and microelectronics. Mr. Dain was previously in the Automation Division.

**D. F. Downie** has been appointed product manager of the newly formed Computer Peripherals Division at S.E. Laboratories (Engineering) Ltd (part of the EMI Group). Mr. Downie was previously in the EMI Central Research Laboratories, where he managed the development of the new S.E. Labs. alpha-numeric display terminal.

**Ted Tingay**, who joined Guest International Ltd two years ago, has become marketing manager with the Industrial Electronic Components Division. He has latterly been product promotion manager. Before joining Guest Mr. Tingay was with Ether Ltd, of Stevenage, for one year as a sales engineer and prior to that spent 12 years with Thorn Electrical Industries Ltd as a development engineer.

**Dr. P. Feltham**, formerly Reader in the Physics Department of Brunel University, Uxbridge, Middx. has been appointed to a new Chair of Applied Physics at the University. He is known internationally for his work in the field of metal physics and semiconductors.

**Jack R. Piddington**, O.B.E., M.C., has joined Electronic Facilities Design Ltd, electronics consultants and systems designers of Wargrave, Berks, as chief executive. He was formerly assistant director of electronics research and development (telecommunications) at the Ministry of Aviation.

## OBITUARY

**John Alexander Ward**, chief engineer of Data Recognition Ltd, died recently at the age of 32. He began his career with Solartron Ltd, where he was one of the small team of British pioneers working on the development of document reading machines. He later joined Montague Burton Ltd as the senior engineer in charge of the operation and further development of their optical mark reading equipment. He joined Data Recognition when it was founded in December 1966 and was responsible for all the electronic and logic circuit design for the company's OMR systems and equipment.

# Real & Imaginary

by *Vector*

## Off the record

There are two schools of thought about birds—the feathered, not the mini-skirted variety—and in particular their irresponsible summer habit of performing a dawn chorus long before the aforesaid dawn has arrived. Some citizens rave about it. I know several who think nothing of rising at some ungodly hour to crawl through half a mile of ditches and brambles to get the maximum number of dBs. Others, however, awakened by the first twitterings, twist restlessly between the sheets, cursing the day they forsook the bright lights for the rural life.

Myself, I'm a sort of floating voter between the two viewpoints. You will not find me out and about at 04.00 to capture the mating call of the lesser spotted milkboy; but neither do I lie infuriated in my bed, stuffing my ears against the fluting and screaming from without, for the simple reason that I sleep through it. At least, I did until this morning when a maniac cuckoo chose to practise his circuits and bumps from my bedroom window-sill and banished all sleep in so doing.

Now, ordinarily I have a great respect for cuckoos and in particular for their laudable habit of laying eggs in an alien nest and then zooming off, leaving somebody else to do the dirty work. I always feel that in their next existence they will take human shape and grow up to be group chiefs or lab. managers. As knocker-uppers, however, they do not have my vote. I mean, one can fling a shoe at a caterwauling cat with a reasonable probability of the missile landing in the target area—but how does one deal with an erratically-flying cuckoo? To design a radar-controlled shot-gun with a cuckoo-voice-operated firing mechanism seems to me to be carrying the matter a shade too far.

The incident did, however, fulfil one useful purpose. It served to remind me of a letter received from a reader whose identity shall be shrouded in the initials 'S.T.C.' (no connection with Standard Telephones & Cables). The cloak of anonymity is one of which I'm sure he will approve, since if it were removed the full majesty of the law would clamp a firm hand on his shoulder.

It seems that S.T.C. has purchased what was described in the small ad. as a "record-player transmitter". I haven't

seen this device but presumably it is a low-power oscillator with sockets for applying external modulation and some form of output that is capable of radiating over a very limited range. I would guess that its radiation is in the m.f. or possibly h.f. band, because S.T.C. says that he uses it to provide music from his indoor tape recorder to his transistor radio in the garden on warm summer afternoons.

He is, of course, fully aware that he is, to all intents and purposes a pirate transmitter but as he has been using the device for a year or so now without attracting the attentions of a Post Office detector van it is obvious that the device is used with restraint and causes offence to no one. Which is more than can be said for electric bells and unsuppressed car ignition systems. Spark transmission was made illegal donkey's years ago but, illogically, no legal steps can be taken to compel a car driver to fit suppressors and cease transmission.\* The electricity cables, too, are notorious radiators of interference and can carry man-made static over many miles without let or hindrance; yet it is illegal for a re-diffusion service to use the electricity mains for programme transmissions.

What brought me, via the dawn chorus, to S.T.C.'s letter was his mention of another project of his, namely the enjoyment of his local bird choir at a reasonable hour of the day. What he proposes to do is to plant a microphone and his "record player transmitter" in an appropriate thicket and connect his home radio to his tape recorder. The two latter devices could be switched on automatically at the requisite ungodly hour and the consequent recording could then be enjoyed later.

He goes on to point out other instances in which the eleventh commandment—"Thou shalt not be found out"—operates. The recording of B.B.C. programmes, for instance, is illegal but (he says) in a radio talk on hi-fi a year or so ago it was mentioned that of all the uses to which tape recorders are put, over half the recorded material is of radio programmes. He also instances the fact that it is illegal to re-record discs and yet most tape recorders

\*Since 1953 it has been obligatory to fit suppressors on all new cars and it is an offence to remove them. ED.

have sockets for doing this and include instructions in their manuals. Indeed, the record players themselves very often have sockets inscribed "Tape" (I've just looked at my own, and it has). So we have a situation in which the record manufacturers frown on the practice of tape recording from their products, but are also manufacturers of record players which directly invite one to do so!

S.T.C. also mentions another way in which he may, or may not, be falling foul of the law. For good and sufficient reasons he does, on occasion, record telephone conversations. I haven't consulted the Post Office but I imagine that it all depends on how you go about this. The automatic telephone-answering device is in widespread use, so any Post Office-approved method of carrying out the operation is presumably valid for normal private conversations.

As my correspondent mentions, recording from the telephone raises the larger and far more serious issue of bugging and snooping. Does much of this go on in industrial concerns I wonder? Certainly one does not read of specific instances in the papers, but possibly this is because firms which have been victimized do not wish their business to be further noised abroad. On the other hand, dire hints of widespread malpractice have been given, both in the Press and on television. I would have thought, however, that a simpler and less 'Paul Temple' approach to industrial spying would be to cultivate the acquaintance of a selection of key secretaries and, after judicious wining and dining, take it from there. I'm not in any sense disparaging the sense of loyalty of the bosses' secretaries, but many are inadequately paid in relation to their responsibilities and a cash-down offer of, say, £50, to a girl who is struggling to make a Majorcan holiday on a weekly income of perhaps £15, would be a considerable temptation. Most, I'm sure, would resist it, but there are bound to be exceptions. Telephone bugging, the picking of filing cabinet locks and the photographing of documents with a micro-min camera is glamorous on TV but in real life the insertion of an extra carbon when copying a confidential document is much less likely to be spotted.

But to return to the anomalies of the law in the matter of illicit transmitters and tape recordings. If S.T.C. continues to use his illegal "record player transmitter" he is liable to have the Post Office running him in for illicit transmission of programmes. But if, by way of revenge, he installs an electric motor with the dirtiest brushes and commutator he can find, the most the P.O. can do is to knock on the door and ask politely if they may inspect it.

The trouble is, I suppose, that the law is not only an ass but a mechanical ass. Its regulations have to be designed to protect the commonsensical majority from the knavish minority. If no curbs on signal radiation were made, the frequency bands would be in chaos; if the same law makes criminals of responsible electronics engineers in the process, it's just too bad.

Anyway, S.T.C., many thanks for a most interesting letter.



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