Wireless World

Broadcasting — retrospect and prospect

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This month the B.B.C. celebrates fifty years of broadcasting in the U.K. In an article in this issue we briefly review the history of broadcasting and list some of the technical highlights and in another article, a contributor illustrates some of the receivers of the early days of broadcasting. Both of these articles look at the past and nobody will gainsay the tremendous contribution to world broadcasting standards that the B.B.C. engineers have made. Not only have they maintained a very high standard of radio engineering practice in this country but they have made an inestimable contribution to the international scene, both in sound and television broadcasting.

What of the future? One of the major problems facing broadcasting engineers today is that of finding a solution to present overcrowding of the radio spectrum. Several of the papers at the International Broadcasting Convention recently held in London touched on this problem. Some speakers saw in direct satellite broadcasting the answer to many, if not all, of the problems. One paper by J. D. Parker of the Columbia Broadcasting System, New York, outlined a proposed satellite system for domestic television programme distribution in the United States. Many of the problems likely to be met with in such a scheme seem to be administrative rather than technical. One thing is certain, there is no overcrowding in the 4-14 GHz part of the spectrum, so frequency allocation is unlikely to create any particular difficulties.

However, in the m.f. and l.f. bands, especially in Europe, the situation is nothing short of chaotic. Dr. H. Rindfleisch, of Norddeutscher Rundfunk, Hamburg, pointed out in his I.B.C. paper on the future of sound broadcasting in Europe that whereas the Copenhagen Plan (introduced in 1948 and still operative) provided for 600 m.f. transmitters in Europe, with a total power of 16,000 kW, there are now some 1,360 stations operating with a total power of 54,500 kW. Moreover, European broadcasting can no longer be considered in islolation. The tremendous growth of the emerging countries of Africa and Asia, and their demands for frequencies, makes an inter-continental conference — European, African, Asiatic — essential. It is understood that such a conference is to be called in 1974 to "reach a fundamental reorganization of the whole frequency range". Suggestions have been made in recent issues that consideration should be given to the adoption of single sideband operation but this would, of course, render existing receivers obsolete, or certainly obsolescent, unless, as suggested by one correspondent in a recent issue that the compatible single-sideband system (c.s.s.b.) be adopted.

Many believe, however, that the fundamental problem is one of channel utilization which is the root cause of the present chaos. When one considers the number of channels (m.f. and v.h.f.) on which, for instance, a B.B.C. programme is radiated it cannot, by any stretch of the imagination, be termed economic in frequency usage. What is true of this country is also true of very many other countries in Europe; a service is radiated simultaneously in the l.f., m.f., and v.h.f. bands and on many different frequencies, particularly in the m.f. band.

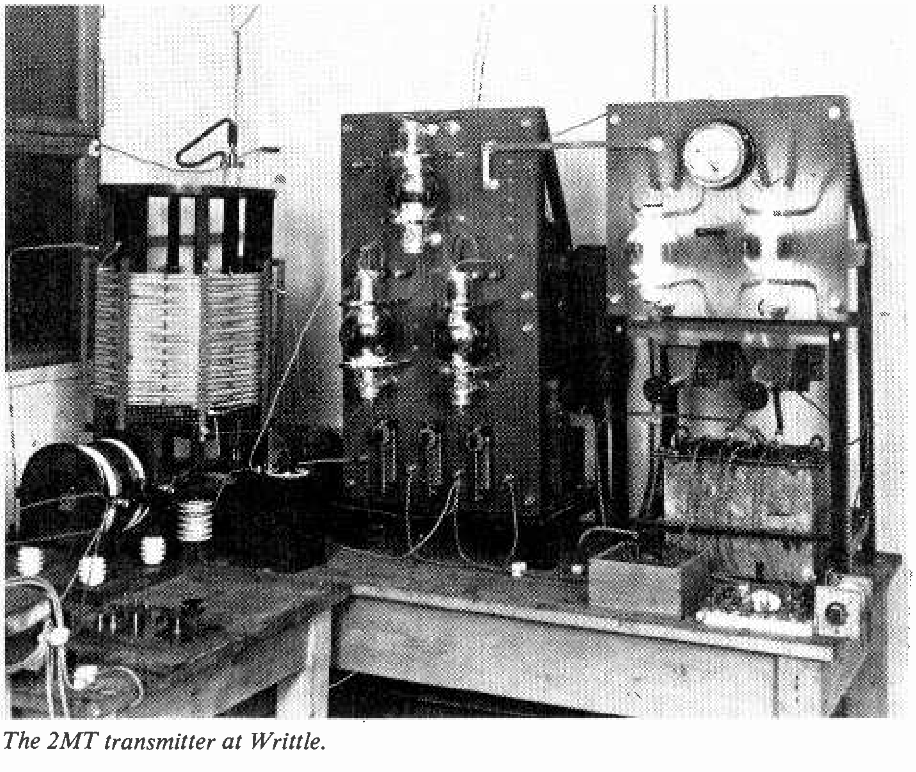
It is obvious that few, if any, countries are going to be given more frequencies than they use at present (whether legally or illegally) if and when there is a reallocation of the m.f. band. We would suggest, therefore, that the whole question of channel utilization should be reconsidered. With the growing use of the v.h.f. broadcasting band, particularly in Germany, should not the m.f. band be utilized for extra-territorial broadcasting, giving each country one or two frequencies in this band exclusively for cultural or, perhaps to be more honest in the use of words, propaganda transmissions? Very-low-power m.f. stations could be permitted for local broadcasting to supplement the v.h.f. band but, by and large, the m.f. and of course the l.f. bands would be primarily used for external broadcasting. Such a reallocation based on the use to which a frequency is to be put might, of course, call for policing of the bands. If this is abhorrent to libertarians we would remind readers that in the United States the Federal Communications Commission has power to withdraw a frequency from a station operator if it can be shown that it is not being fully utilized.

British Broadcasting

B.B.C. jubilee: some historic technical events

The genesis of broadcasting in the U.K. is rooted in the enterprise and initiative of the Marconi Company and the interest and persistence of the amateur radio fraternity. The first major experiment which, although primarily intended for reception in particular places, had the character of broadcasting, was conducted by Marconi's early in 1920. A 15-kW station at Chelmsford transmitted speech and music for two periods each weekday for about a fortnight in February/March 1920. This brief experiment was followed by the now famous Dame Nellie Melba broadcast, on June 15th 1920 from the Chelmsford station broadcasting on 2,800 metres, which was sponsored by the *Daily Mail.* There were other occasional broadcasts during the summer of 1920 but the experiments ceased, apparently, it would seem, because the Post Office refused to license further broadcasts. In his book "The Power Behind the Microphone" P. P. Eckersley (who was at the time head of the experimental section of Marconi's designs department and later chief engineer of the B.B.C.) states that the Post Office wrote to the Marconi Company saying that "the experimental broadcasting transmissions must cease because they were interfering with important communications".

Although officially "broadcasting" had therefore been stopped in this country, considerable activity continued within the amateur fraternity. In our November 25th 1922 issue in which we published a "History of the Wireless Society of London" (now the Radio Society of Great Britain) we wrote "In the London district there had been few evenings . . . . since 1920 without entertainment of some kind – all this, however, on low power and, in so far as it was broadcasting, technically against the law". There were, incidentally, also concerts broadcast from the Hague on 1050 metres (started in May 1920) and from the Eiffel Tower on 2,200 or 2,600 metres (from late 1921) which could be received in this country.



The 2MT transmitter at Writtle.

Early in 1921 the Marconi Company had applied to the Post Office to transmit for a mere half-hour or so a week a programme of telegraphy and telephony. The Post Office, however, did not like the application coming from a manufacturer as the granting of such permission would give the Marconi Company preferential treatment. The Post Office stated that "it would come very much better from the Wireless Society"! In August 1921, however, Marconi's were allowed to transmit telegraphy for amateur reception but permission for telephony was still withheld. Our pages in late '21 included many letters from amateurs urging that telephony transmissions should be started in the U.K. and it was about this time that *Wireless World* launched an appeal for subscriptions to enable the concerts from the Hague to continue (about £750 was subscribed). As a result of a petition to the Post Office at the end of 1921 on behalf of 3000 or so members of 63 wireless societies voicing "a national resentment that public services such as wireless Time and Telephony should be left to our neighbours to provide" the P.M.G. authorized Marconi's to include "a programme of 15 minutes telephony (speech and music) in the weekly transmission from their Chelmsford station for the benefit of wireless societies and amateurs". So began on February 14th 1922 the first regular and advertised broadcast programmes in this country. The story of the Writtle, Chelmsford, station 2MT, supervised by that inimitable engineer P. P. Eckersley, is well known. The transmissions, under the direction of the Marconi Scientific Instrument Company, were radiated on 700 metres, initially from 19.35 to 19.55 with 15 minutes "actual transmission of music etc with 2 minutes interval between selections". The approximate power was $\frac{1}{4}$kW. Commenting on the first transmission (see photograph) we wrote in our March 4th issue "Unfortunately experience showed that a considerable amount of jamming took place, particularly from GBL [Post Office station at Leafield], on the wavelength allotted for the telephony transmission, and it is understood that the Postmaster-General has been asked to permit a change of wavelength for this transmission. As we go

204 THE WIRELESS WORLD AND RADIO REVIEW November 11, 1922

The New Licence for Broadcast Reception

BROADCAST LICENCE.

A 41602

WIRELESS TELEGRAPHY ACT, 1904.

Licence to establish a wireless receiving station.

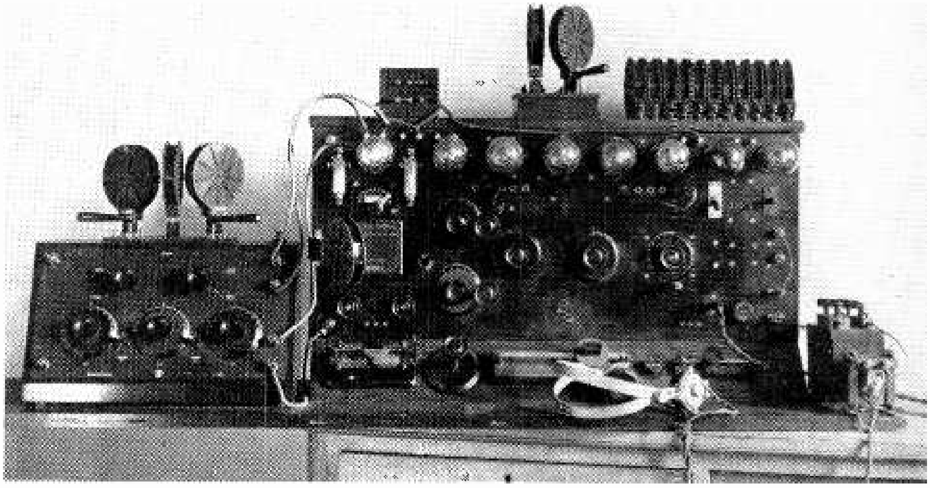
Messrs The Wirelessworld & Radio Review
(Name in full)
of 12/13 Henrietta St. Lon WC is hereby
(Address in full)
authorised (subject in all respects to the conditions set forth [illegible]) to establish
a wireless station for the purpose of receiving messages a[illegible]
...for a period ending on th[illegible] next.
The payment of the fee of ten shillings is hereby acknowledged.
Dated 3rd day of November 1922
Issued on behalf of the Postmaster-General
Signature of Licensee WIRELESS WORLD & RADIO REVIEW.
If it is desired to continue to maintain the st[illegible] date of expiration a fresh Licence must be taken out within fourteen days. Heavy penalties are prescribed by the Wireless Telegraphy Act 1904, on conviction of the offence of establishing a wireless station without the Postmaster-General's Licence.
2801 G & S 194

APPARATUS USED UNDER THIS LICENCE MUST BE MARKED

TYPE APPROVED BY POSTMASTER GENERAL BBC

Stamp of Issuing Office.
BEDFORD ST. STRAND. B.O. 3 NO 22 W.C.

Our first broadcast receiving licence issued two days after the introduction of the licence. Note the overprint "apparatus used under this licence must be marked type approved by Postmaster General".



Constructed in the winter of 1922. This photograph of an eight-valve superhet has been sent to us by Kenneth Alford (G2DX) of Camberley, Surrey. Here are the circuit details he supplied: preselector (V24), local oscillator (V24), six R valves – 1st detector with cathode injection, three i.f. stages at 100kHz (with regeneration), 2nd detector, local oscillator (b.f.o.) and two a.f. stages. The variable capacitors were built up from parts and a plaque was attached to the set stating that royalty had been paid to the Marconi Company in respect of the grid-leak patent.

to press we learn that Tuesday, February 28th, being the date fixed for the Royal Wedding [of the Princess Royal and Earl of Harewood], the Marconi Scientific Instrument Company, Ltd., under whose direction the transmissions are being made, has conceived the happy idea of transmitting appropriate wedding music on that evening, and it is hoped to include the actual music which will be played in Westminster Abbey for the ceremony!"

Reports of reception came from as far afield as Forfarshire, where, using a 5-valve home-built set a reader "got music and speech in a loud speaker audible all over the room". A listener in Liverpool reported "clear reception on a four-wire indoor 12-ft aerial, using a three-valve receiver". Little was then known of propagation problems. Reporting that "a fading off is marked" in Edinburgh those responsible for the transmissions stated "that the aerial amperage during transmission remains practically constant throughout" and, in consequence "attributed the fading to local conditions in the Edinburgh district".

Writing in *W.W.* in November 1969 Pat Hawker stated, "The beginning of regular, scheduled sound broadcasting – certainly in Europe and probably in the world – stems from the concerts and talks broadcast over station PCGG at The Hague. . . . These concerts pre-dated those from KDKA, Pittsburg, which has often been given credit for the start of regular broadcasting . . . The first musical transmission was probably that made by Fessenden on a high frequency alternator station at Brant Rock in 1906".

It was Eckersley's infectious and spontaneous humour which gave 2MT its unique flavour. In his book "Captain Eckersley Explains" published in 1923 "P.P." refers to the suggestion that had it not been for the Writtle transmissions broadcasting would not have got under way in Britain when it did. "While I . . . am much flattered by the suggestion, I am still unconvinced" he writes, adding "Broadcasting came about because those interested came over from the States and pointed out what vast sums of money were being made there, what interest broadcasting was creating, and how England had got left behind. This I think was the great stimulant – American broadcasting. It had nothing to do with the then unhonoured and unsung transmissions, attracting no notice in the ordinary Press, and of which the general public was wholly ignorant. This is not false modesty, it is the truth, and while, of course, the Writtle transmissions may have raised to fever pitch the enthusiasm of real wireless amateurs I think it did little to attract general notice".

In his book "British Broadcasting — a study in monopoly" R. H. Coase confirms the truth of this analysis, pointing out that within days of the start of the Writtle transmissions and before any conclusions could be drawn from the experiments, a number of radio manufacturers had applied to the Post Office for permission to broadcast. He adds "The reason for these applications is quite clear. Experience in the United States had shown that there was a large market for receiving sets once a broadcasting service had been provided. Radio manufacturers were therefore anxious that a broadcasting service should be established in order to create a demand for their receiving sets". The larger companies divided themselves into two groups to produce a co-operative scheme for broadcasting. One group consisted of Marconi's, G.E.C., and British Thomson Houston; and the other Metropolitan-Vickers, Western Electric

Rex Palmer ("Uncle Rex" of Children's Hour) using a Round-Sykes microphone (note the switch) at Savoy Hill.

The almost domestic atmosphere of an early studio.

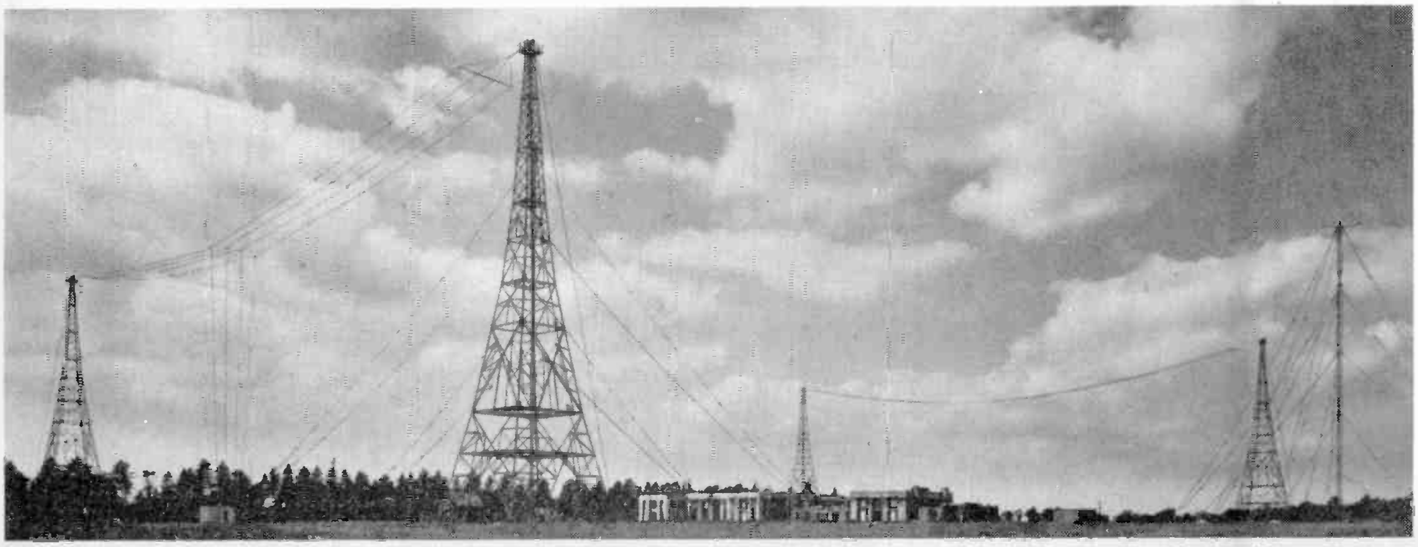
Professor Fulton demonstrating the reception on a Fultograph of pictures broadcast from Savoy Hill.

and the Radio Communication Company. It is interesting to recall that the first four companies mentioned have now been brought together (two having lost their identity) in the G.E.C.-English Electric group. Western Electric is now Standard Telephones and Cables (part of the American ITT group).

After protracted discussions between the two contending groups and the Post Office, agreement to form a single broadcasting company was reached in August 1922. Thus the British Broadcasting Company was formed[*] of which J. C. W. Reith became the first general manager and P. P. Eckersley the first chief engineer.

Several of the major companies in the consortium had installed experimental transmitters during the months preceding the setting up of the B. B. Company. Marconi House, in the Strand, London, housed a 100-watt transmitter (2LO) later raised to $1\frac{1}{2}$ kW; Western Electric had a transmitter at its London office off the Strand, and Metropolitan-Vickers and the

Brookmans Park aerials for the London regional twin transmitters and on the right the later 500-ft mast radiator.



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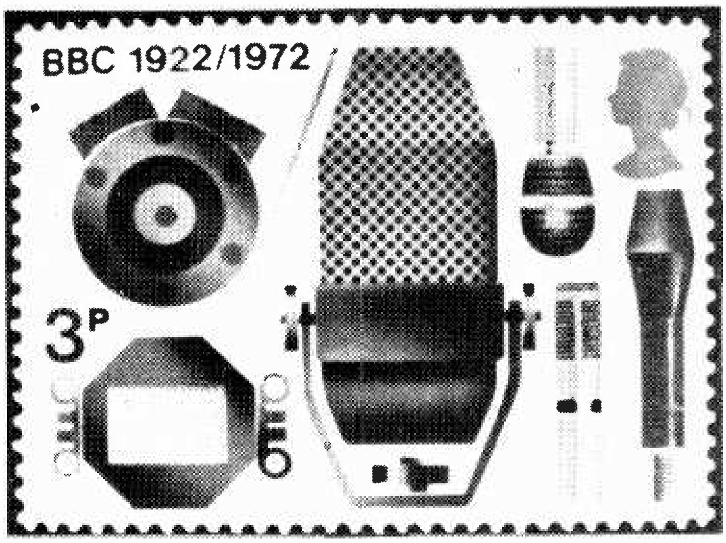
[*] The Company was not formally registered until December 15th 1922.

Radio Communication Company a station in Manchester.

The B.B. Company took over these three stations and broadcasting started from 2LO on 369 metres on November 14th 1922. The following day transmissions began from the Birmingham station (5IT) on 420m and Manchester (2ZY) on 385m. The Birmingham transmitter was that previously installed in the London office of Western Electric which had been transferred to the G.E.C. works at Witton. The station was dismantled, conveyed by road to Birmingham, re-installed and was operational within five days of instructions being received.

So 50 years ago British broadcasting started. Initially it was financed from three sources: the subscribed share capital (100,000 £1 cumulative ordinary shares of which 60,000 were held by the six firms primarily concerned with the broadcasting scheme); royalties on receivers and components; and 50% of the licence revenue (fee 10s). The scale of royalty payments varied from 7s 6d on a crystal set to £1 15s 0d for a two-valve set plus 10s for each "additional valve holder". All receivers had to be type-approved by the Post Office. A specimen receiver was approved by the Post Office, sealed and returned to the manufacturer for reference. Each set sold had to carry an approval stamp (see reproduction of licence).

Within a year the B.B.C. was operating nine medium-wave stations. London 2LO (by now in Savoy Hill), Birmingham 5IT Manchester 2ZY, Newcastle 5NO, Cardiff 5WA, Glasgow 5SC, Aberdeen 2DB, Bournemouth 6BM, and Sheffield 6FL (the first relay station). Several "firsts" occurred by the end of 1923: first outside broadcast ("The Magic Flute" from Covent Garden), first Continental programme by landline (from Radiola, Paris), first broadcast of chimes of Big Ben, and the first simultaneous broadcast by all nine stations.



A selection of some of the microphones used by the B.B.C. is illustrated on this jubilee stamp. Top left: Round-Sykes moving-coil of Savoy Hill days. Bottom left: Marconi-Reisz transverse current carbon type. Centre: B.B.C. ribbon microphone introduced in 1936. On the right are representative types currently used.

We could fill many pages of the journal, indeed several issues, if we were to describe in detail even the more outstanding technical events in the fifty years of British broadcasting (the BBC Engineering Information Service has issued a dossier of 46pp!). However, having painted the background and set the scene for the introduction of broadcasting in this country we will confine ourselves to listing some of the technical events upon which the unequivocally high standards of British broadcasting have been built.

In conclusion we will add our congratulations to the B.B.C. research, design and operations staff on their achievements throughout the fifty years and to thank them for their ever-ready co-operation in providing information for the benefit of our readers.

Calendar of events

First l.w. station, Chelmsford 5XX (July '24). Year later moved to Daventry.

First relay from America — KDKA Pittsburgh (16.11.24).

Round-Sykes moving-coil microphone replaced carbon and capacitive types introduced in 1924.

Tuning fork drive (based on Eccles invention of 1918) introduced in 1924 giving frequency stability of ± 1 part in 10^5.

First international conference on broadcasting convened by B.B. Company in London (18.3.25).

B.B. Corporation constituted under Royal Charter (1.1.27).

First broadcast of the Boat Race from the launch *Magician* using 100-W transmitter (2.4.27).

Chelmsford G5SW started experimental s.w. Broadcasts to the Empire (11.11.27); closed down 17.12.32.

Start of a year's experimental transmissions of still pictures from Daventry using the Fultograph system (30.10.28).

Experimental, vision only, broadcasts of Baird 30-line television using 2LO transmitter (then at Selfridges) began 30.9.29.

Brookmans Park, first twin-wave station of regional scheme, brought into service (21.10.29).

Experimental sound and vision (Baird 30-line) transmitted from Brookmans Park. Vision 261.3m, sound 356.3m (14.3.30).

Blattner-Stille magnetic recorder, using 6-mm tape introduced in 1930.

Broadcasting House, London, brought into use and the first programme meter installed (2.5.32).

Inauguration of Empire service, using two s.w. transmitters and vertical aerials at Daventry (19.12.32).

Watts direct-disc recording equipment introduced (1934).

Last 30-line TV broadcast (11.9.35).

Anti-fading mast radiator used for first time at Lisnagarvey station (20.3.36).

Experimental transmissions of high-definition Television introduced for Radiolympia (26.8.36.-5.9.36). Baird 240-line mechanical scanning and E.M.I. 405-line electronic systems used on alternate days for two one-hour periods.

Ribbon microphone started to replace the Marconi-Reisz in 1936 (see photo of stamp).

Marconi-EMI television system adopted and daily service begun on 6.2.37.

1937 saw the introduction of the Philips-Miller recording system, the lip microphone, super-Emitron camera and the Post Office balanced-pair cable in central London for television O.Bs.

1.9.39. Transmitters arranged in two synchronized groups (for war-time operation to prevent direction finding) radiating a single programme. Television service closed down.

By the end of 1940 sixty low-power stations had been built to improve reception of Home Service.

During 1943 MSS midget disc recorder introduced for war correspondents.

Engineering staff rose from 1674 at the outbreak of war to 3733 (plus 449 serving with the Forces) in 1945.

Television service reopened after war 7.6.45 (licence, including sound, £2).

Experimental v.h.f. comparative transmissions on 90.3MHz (f.m.) and 93.9MHz (a.m.) started from Alexandra Palace in late 1948.

BBC-designed optical standards converter used first time for television programme from Paris (6.7.52).

Wrotham v.h.f. broadcasting station opened 2.5.55.

Colour television test transmissions (NTSC) from Alexandra Palace 10.10.55.

Experimental 625-line band V transmissions from A.P. in November 1957.

Stereophonic test transmissions (13-14.1.58).

Fortnightly experimental stereo transmissions using two stations began 18.10.58.

First video-tape recorder brought into service in December '58.

Transatlantic television via Telstar (11.7.62).

Experimental Zenith-GE stereo transmission on v.h.f. from Wrotham (28.8.62).

Electronic line-store converter was brought into service in 1963.

PAL colour TV test transmissions started 24.5.65.

P.M.G. authorized on 3.3.66 introduction of colour system on BBC-2. Full PAL colour service began 2.12.67.

First programme use of field-store converter (31.8.67).

CLUE (automatic camera line-up equipment) installed by B.B.C. in 1968.

First landing on the moon televised (21.7.69).

Sound-in-sync demonstrated in 1970.

Some Early Radio Receivers

An illustrated survey, with notes on performance and operation

by A. M. Peverett, M.I.E.E.

Since the B.B.C. started broadcasting in 1922 there have been considerable changes in receiver design. This article takes a look at some of the early receivers made between 1923 and 1935, which are in the author's collection, and comments on how well they perform today.

Crystal sets used a very simple circuit design as selectivity was not important then, but operating under modern crowded wavelength conditions obviously presents a problem; indeed it is often impossible to separate the stations at all. A long aerial and a good earth are normally essential for adequate audio output (unless the receiver is very close to the transmitter) and a considerable amount of patience is required in order to find the best position of the cat's whisker on the crystal. Having found it, there is always a terrible temptation to see if one can do better. This invariably results in a further frustrating ten minutes or so to achieve the same results as before!

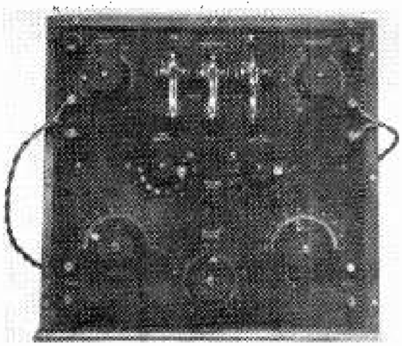
It might be thought that a modern germanium diode, used in a crystal set, would be far superior to the cat's whisker. However, substituting a Mullard OA70 in place of one of the crystals in the Rexophone illustrated gives approximately the same audio output compared to the *optimum* setting of the cat's whisker. These early crystals were normally made from galena (or lead sulphide), the cat's whisker itself usually being a piece of fine silver wire coiled at one end to give it a certain amount of spring.

Not all receivers in 1923 were crystal sets. Indeed the Marconi Scientific Instrument Company was producing 2- and 3-valve battery receivers (together with additional amplifiers to drive a speaker if required) as well as even more sophisticated units with built-in speakers.

Performance of the Marconi 3-valve set illustrated is excellent and in its day it must have been outstanding. However, in order to locate stations reasonably quickly it has been necessary to draw up a list of the eight control settings for each transmitter! Unfortunately some of these settings are affected by the length of aerial, so the list only serves as a rough guide.

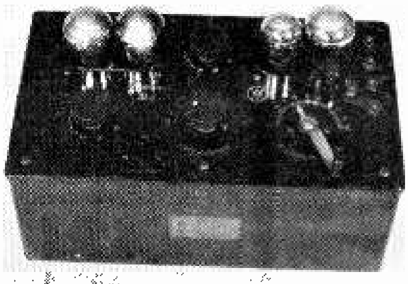
Selectivity can be adjusted to a certain extent by careful use of the reaction control, the best selectivity obviously being close to the oscillation point.

1923: Rexophone crystal set. Two crystals, adjusted before programme; if one knocked off "tune", other can be switched in. Coil resonance adjusted by 12 coarse and 12 fine taps brought out to studs on panel. Loading coil to lower frequency brought in by means of removable link wired in series with tuning coil. Headphones, 2000Ω per earpiece.



1923: Marconi 3-valve receiver; r.f., detector, a.f.; headphones. Bright emitter triodes, filament voltage adjustable around 4V, anode voltage 27V, current 0.9A each, amplification factor 5. Coverage 150kHz-1.5MHz, using tapped inductors, variable capacitors. Reaction control by movement of inductor. Grid leak, two pencil lines on sheet of ebonite. Bias to r.f. stage adjustable. Eight controls needed for frequency change.

1923: Gecophone BC1001 crystal set. Tuned by variometer: two coupled coils, one inside the other and electrically connected; rotating the inside coil causes them to be mutually aiding or opposing. Two aerial inputs, one direct to variometer, the other via a 250pF capacitor. Removable link for adding loading coil. Four sockets allow use of either one or two pairs of headphones.



c.1923: Canadian Westinghouse Radiola IIIA. Four valves. Tuning by variometer (see Gecophone). Detector, a.f. stage, push-pull output. Not yet in working order.

Because of this, quite good reception of Radios 1 to 4 can be achieved at night time (particularly Radio 2 on l.w.) as well as Radio Luxembourg and other foreign stations.

This set, and the two crystal sets illustrated, have the original "BBC" emblem (representing British Broadcasting Company) surrounded by the words "Type approved by Postmaster General".

The quality, using Ediswan headphones of the same period, is acceptable; however, I must admit I was tempted to try modern Sennheiser hi-fi high-impedance headphones, and then the quality is unbelievably good. Indeed it seems impossible that this set was made almost 50 years ago! It originally cost £30, excluding batteries.

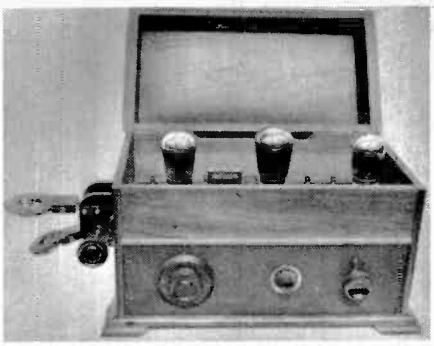
By the late twenties the screen-grid valve had taken over from the triode in the r.f. section of the t.r.f. receiver and pentodes were now used in the output stage, usually driving moving-iron loudspeakers. Commercial mains receivers began appearing in reasonable numbers during this period. A few had been built prior to this but there were problems with early indirectly heated valves, one of them being grid emission. This was due to the grid becoming coated with small particles from the cathode; as the grid tended to run very hot in the early mains valves (partly due to bias problems) grid emission occurred. However, this and other problems such as poor heater-cathode insulation (which had prevented the use of cathode bias resistors) had now been overcome.

One big advantage of the mains receiver, quite apart from the elimination of batteries which had previously made the receiver fairly costly to run, was the increased audio power output available, as in a mains receiver current consumption was obviously no longer a major problem. This meant that normally about 1 watt of audio power was now available to drive a moving-iron or a moving-coil speaker.

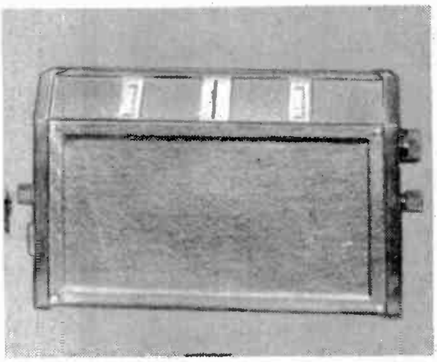
By 1930 selectivity was becoming increasingly important because of the large number of transmitters appearing in the m.w. band. The superhet circuit, owing to problems encountered in the early days, was still not popular here (although it was on the Continent), and so the tendency was to increase the number of tuned circuits but still retain the t.r.f. configuration. At the same time the number of front panel controls was being reduced in order to make the receiver simpler to operate. Thus 2- and 3-gang tuning capacitors operated by one knob began to make their appearance.

During the early '30s in the U.S.A. many receivers were being designed almost as pieces of furniture. The Brunswick model 15 receiver (illustrated) is a fine example. The cabinet is magnificent and the technical design was advanced for its day. Unfortunately no allowance appears to have been made for adjusting the inductance of the tuning coils, so that tracking is lost somewhat at the low-frequency end of the m.w. band.

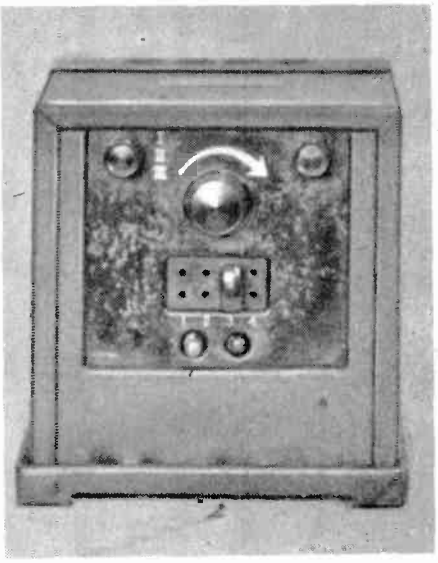
Because of the selectivity difficulties



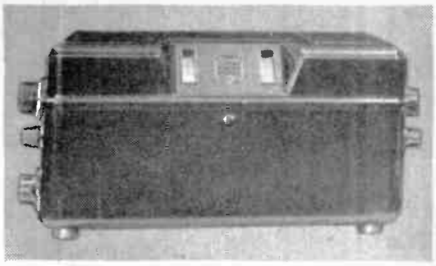
Mid-1920s: 3-valve receiver, probably made from a kit. Note the swinging reaction coils on outside of mahogany case.



1928: Philips 2502, 3-valve battery set (mains, 2514, and mains/battery, 2501, versions also). Screen-grid h.f. stage, triode detector, pentode output. Separate loudspeaker and matching transformer. Aerial and anode circuits tuned separately. Three aerial sockets with different capacitors for varying selectivity and sensitivity. Four-position wave-change and on/off switch. Tuning, reaction and volume controls on side of cabinet.

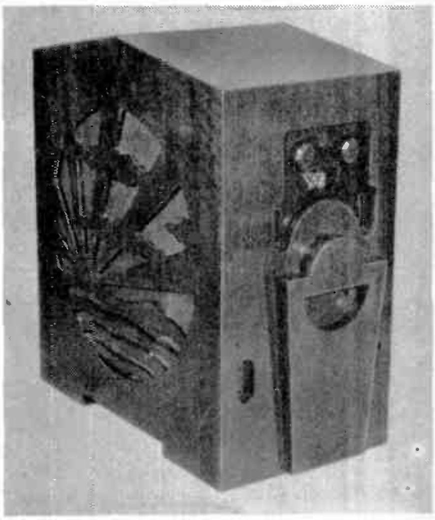


1928: Philips 2515, two valves (detector, a.f.) and rectifier mains receiver. One tuning control, reaction control using variable coil coupling, 4-position aerial plug controlling selectivity. Metal cabinet $7\frac{1}{2} \times 7\frac{1}{2} \times 10\frac{1}{2}$in. Separate loudspeaker, pickup sockets but no volume control. Price £12 10s.

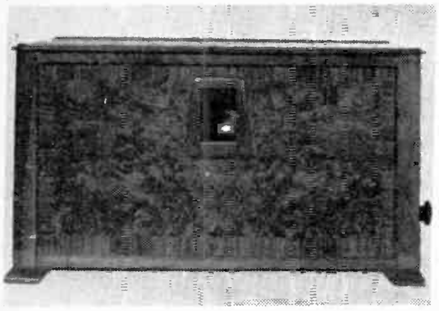


1930: Philips 2531 mains set, re-styled 2514 in plastic cabinet. Top opens to allow access to chassis and automatically disconnects mains. Waveband coverage 200-450, 400-950, 900-2100 metres. Dial lights. Sound quality improved on Philips 1928 sets.

1930: Brunswick (U.S.A.) model 15, illustrating "furniture" approach in console cabinet design; t.r.f. circuit; four screen grid valves in r.f. and detector stages, with 4-gang capacitor; two triodes in parallel for a.f. Loudspeaker energizing coil acts as a.f. choke in anode circuit; audio signal via capacitor to output transformer. Good sound quality with pronounced bass response.



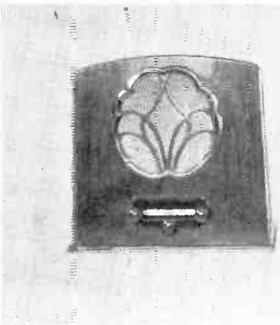
1931: Pye "transportable" MM, weighs nearly 40lb. Three-valve plus rectifier t.r.f. mains set. Built-in frame aerial (set tuned for maximum signal pick-up and selectivity). Two-gang tuning covers m.w. and l.w. Fine tuning trimmer capacitors across aerial section of ganged capacitor. Moving-coil loudspeaker.



c.1931: Gecophone BC 3240, 3-valve plus rectifier mains receiver in walnut cabinet. Separate moving-iron loudspeaker with sharp cut-off above 9kHz; sound quality not as good as 1931 Pye MM.

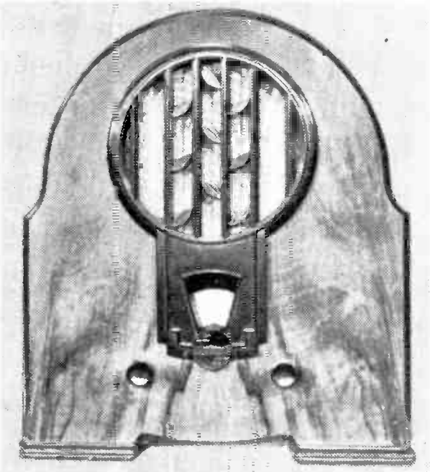
1931: H.M.V. 501, 3-valve plus rectifier t.r.f. table radiogram. Three-gang tuning, bandpass aerial circuit, series aerial trimmer (control on side) and reaction (control on other side). Illuminated dial on motor board. Pickup tracking weight 200 grams. Lid has felt lining to reduce mechanical noise. Power unit has resistive smoothing – probably reason for some mains hum.

1931: H.M.V. 436 table mains receiver, similar in circuit design to H.M.V. 501.

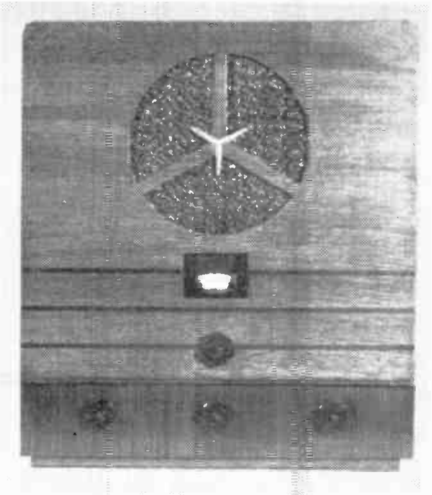


1931: Marconi 253 table mains receiver, similar in circuit design to H.M.V. 501.

1932: Ekco SH25 superhet. Selectivity allows station names on dial surrounding speaker. 110kHz i.f. and 110kHz aerial filter; bandpass aerial tuning; pentode frequency change/biased as anode bend detector, oscillator voltage to cathode; "local/distant" switch introduces damping in i.f. (no a.g.c.); volume control adjusts i.f. valve bias and aerial circuit damping; control for cancelling second channel; pickup sockets.

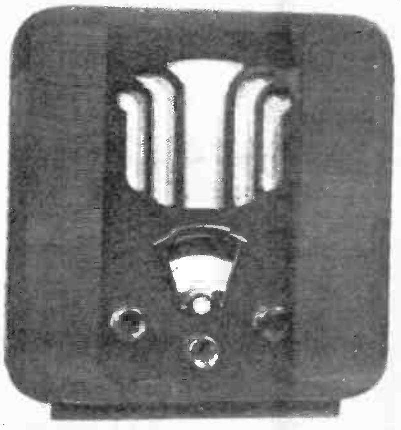


1933: Philips Super Inductance 634A t.r.f. receiver. Four-ganged r.f. tuned circuits; each section of tuning capacitor in screening can. "Super Inductance" refers to large coils, low-loss, using Litz wire on glass formers, screened by cylindrical copper cans. Performance comparable with early superhets, but manufacturing costs probably high.



1933: Murphy A4 superhet. Aerial bandpass tuning; second-channel suppression; mixer AC/Pen valve with screen used as oscillator; i.f. 117kHz, volume control and detector similar to Ekco SH25. Power supply smoothing choke has 0.1μF capacitor in parallel to resonate at 100Hz.

c.1933: Micro-Perophone table radiogram (minus pickup). Regentone superhet chassis. Compact synchronous motor (not self-starting), windings mounted on underside of motor board, which is hinged and folds downwards. Speaker behind metal casing enclosing turntable, sound being reflected through front ports around periphery of cabinet.



1934: Philips Super Inductance 274A t.r.f. set, simpler than Philips 634A.

mentioned earlier — and also perhaps because of radiation problems if a t.r.f. receiver was used with too much reaction (causing all the receivers close by that were tuned to the same frequency to howl!) — the superhet finally returned to commercial popularity in the U.K. around 1932.

The early superhets of the twenties had got a bad name for poor quality plus the fact that they suffered from a considerable number of heterodyne whistles. The former was partly due to rather narrow passband i.f. transformers causing sideband cutting, although often it was also due to poor a.f. transformer design, etc. which had nothing to do with the superhet type of circuit. The heterodyne problem was mainly caused by poor second channel selectivity; this was not made any easier by the fact that, in order to achieve maximum amplification with early valves, the i.f. was deliberately kept to about 50kHz. As valves improved so did the amplification at higher frequencies. Therefore the superhet circuit was dropped, as selectivity in the early days was hardly a major problem and furthermore the extra valves that the superhet required considerably increased the current drain.

When the superhet returned to popularity about 1932 a higher i.f. was used (normally 110-117kHz). Bandpass aerial tuning was also adopted, in order to improve second channel selectivity. This meant the use of a 3-gang capacitor, the third section being used for oscillator tuning. Although heterodyne whistles which had plagued the early superhet were still occasionally a problem on a few receivers, by and large the beast had been tamed!

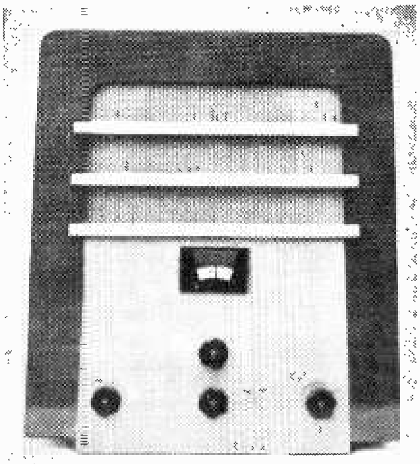
In conclusion, it is fair to say that the Regentone SW45 and the Murphy A24 illustrated represent early examples of the valve superhet circuit, respectively with and without an r.f. stage, that survived almost unchanged for more than 25 years until the advent of the transistor radio in the early sixties.

Loudspeakers

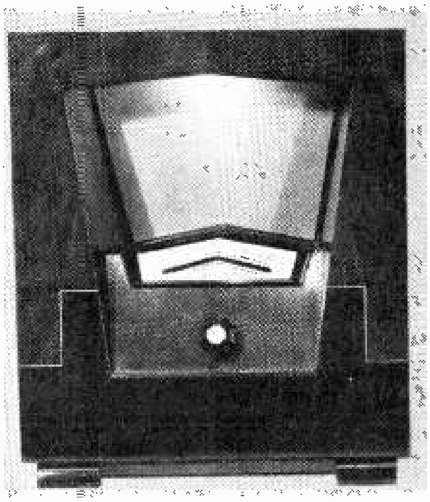
Three early types of loudspeakers are illustrated. The Amplion RSIM was an early moving-iron speaker of the mid-twenties and used horn loading, the drive unit (together with a centring device) being fitted at the bottom of the cabinet. Its frequency response is very restricted, covering approximately 100Hz to 5kHz.

The Ultra Airchrome speaker was a moving-iron unit made in 1929. It had two fabric cones, one mounted behind the other, the one at the rear being about half the size of the front one and presumably acting as a "tweeter". Certainly its response is much better than the Amplion, covering approximately 50Hz to 9kHz.

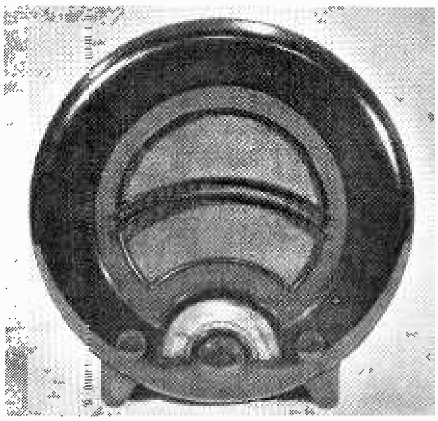
An early moving-coil speaker was the Marconiphone unit of 1929. It used a massive energizing coil which operated off a 200V d.c. supply. Unfortunately, it is not really in a good enough condition to judge its audio quality.



1934: Murphy A24 superhet. Triode pentode mixer; i.f. 117kHz; double diode triode a.f. stage, one diode as main detector, other as detector in amplified delayed a.g.c. Volume control now in "standard" position between valves mentioned, usable also with pickup. Resonant smoothing choke. As in A4, many resistors and paper capacitors enclosed in metal box with tag strips.

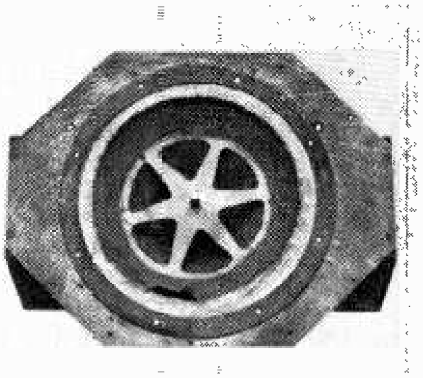


1934: Regentone SW45 superhet; r.f. stage, triode pentode mixer; delayed a.g.c. operates neon tuning indicator. No a.f. amplifier; a.g.c. and detector diodes in output pentode. Moving-coil speaker set back in cabinet with reading light in front. Working for 37 years and only just retired.

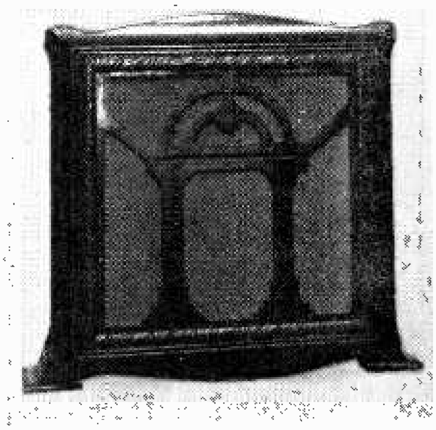


1935: Ekco AD36 t.r.f. receiver, a.c./d.c. mains.

Amplion RSIM loudspeaker.



Ultra Airchrome loudspeaker.



Marconiphone moving-coil loudspeaker.

Circards 2

Switching Circuits

Comparators, Schmitts and level-sensors

*by J. Carruthers, J. H. Evans, J. Kinsler & P. Williams**

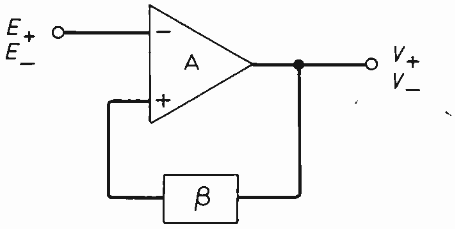
There is a need for circuits whose output changes by a large amount as the input passes through a particular level. There are four cases:

1. The change may be reversible without hysteresis, and those high-gain amplifiers called comparators belong to this class.
2. The change may be reversed at a different value of input, i.e. exhibit hysteresis, and Schmitt trigger circuits are examples. The output may fail to return to its original value when hysteresis is present, because the input is constrained within limits preventing such reversal, and such circuits are said to "latch".
3. The output, because of some intervening unidirectional device or circuit, may remain in its second state indefinitely regardless of any further excursions of the input unless returned to its original state by some alternative process, and bistable circuits such as the classic Eccles-Jordan belong to this category.
4. Finally, the circuit may respond to the second or succeeding excursions of the input through a given level in a given sense, and such circuits are used for dividing and counting in logic systems.

In types 3 and 4 above, the normal applications are such that precision of switching level is unimportant, as the systems in which they are used are digital, generally binary. Hence the input and output levels, need only be controlled within broad limits and can still be identified unambiguously. While precision in the switching levels may be combined with these other functions it is more usual to separate the functions as design constraints are so different.

Switching circuits to be considered here belong to types 1 and 2 above and can constitute an interface between analogue and digital systems – discrete changes in output are obtained at specified amplitudes of input.

Type 1 may be further sub-divided according to whether the input is differential or single-ended with respect to some prescribed level, often ground potential. The former is readily available in the form of integrated-circuit comparators with excellent performance. Early versions were designed for high-speed operation to be used in conjunction with particular logic families. Supply voltages are required to be within close limits of specific values not always compatible with those in common use for other purposes, e.g. +12/−6V as against ±15V for many analogue systems. For this reason newer versions have appeared capable of working from a wide range of supply voltages, and having lower input current requirements. Yet others are being produced with higher switching speeds.



$$E_+ = \beta V_+ \qquad E_- = \beta V_-$$

$$(E_+) - (E_-) = \beta\left[(V_+) - (V_-)\right]$$

Voltage gain of these comparators is high, with the full output swing being achieved for an input change of a few millivolts. Thus if one input terminal is taken to some constant reference voltage with the other input fed from the signal source, a sharp output transition occurs when the signal voltage exceeds that of the reference. Finite voltage gain together with offset (unbalance) effects limit the precision achievable at low cost to a few millivolts.

How to obtain Circards

Order Circards direct from the publishers by sending remittance (£1 per set, including postage) to "Circards", *Wireless World,* Dorset House, Stamford Street, London SE1 9LU, indicating which set you are buying. A limited number of series 1 (12 cards) entitled "Basic active filters" is still available. Apply early as print order is limited.

The Circard concept was outlined in the October issue, which included an introductory article to the first series.

The indeterminate value of output for inputs close to the reference level, makes the use of low-gain amplifiers inappropriate as comparators, and discrete circuits with two or three transistors are less commonly found as type 1.

If positive feedback is applied to any amplifier then under the right conditions the output can be made to switch between two distinct states with little or no further change in output regardless of further variation of the input. This applies to low- and high-gain amplifiers alike, though with the former the magnitude of the feedback factor must be larger to ensure a complete switching action. The margin must be large enough to guarantee the switching action in the presence of parameter variations due to supply and environmental changes for a particular unit, and to cover component tolerances.

A further property resulting from the use of positive feedback is that the output transition in the positive and negative inputs occur at different values of input – the effect being called hysteresis of the circuit. This is illustrated in the figure where V_+ and V_- are the alternative output voltages of a comparator (or operational amplifier where high speeds are not critical) when fully switched. The input voltages E_+ and E_- are the voltages at which transitions occur. The output will switch from V_+ to V_- when the input exceeds βV_+ by a small amount of the order (V_+/A), where β is the fraction of the output voltage fed back and A is the voltage gain of the comparator in its active region.

Hence the hysteresis is obont $\beta\Delta V$, where ΔV is the change in the output, and provided A is large.

In various applications it may be necessary either to minimize the hysteresis or to increase it and define it. The former requirement indicates the need for a high value of A; the latter for an accurately defined product $\beta\Delta V$ and either large A or at least a defined value of A. Deciding on the precise value of A to be used in such calculations is difficult — the gain continually changes as the critical point is approached. Using i.c. comparators (or operational amplifiers at lower frequencies) the value of A is sufficiently high that the hysteresis can be defined by the resistive feedback network.

Discrete amplifiers, of which the Schmitt trigger is the classic version, are capable of a very wide range of characteristics with complementary versions increasing the choice of characteristics. A problem frequently encountered in such designs is that the switching levels, hysteresis etc, are often interdependent and have to be preselected using suitable algebraic equations. It may not be easy to achieve independent control of these parameters.

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*All with Paisley College of Technology

An I.C. Peak Programme Meter

by L. Nelson-Jones, F.I.E.R.E.

A design using standard i.c. operational amplifiers to achieve a transformerless design to the specification of the British Broadcasting Corporation, who pioneered this type of level indicator. Mono or stereo applications are catered for in the design, with separate or common meter indication. The circuit is stable against temperature and supply voltage variations, and is designed for use with a nominal 24V supply (16–30V). The main design aims were to obtain accuracy, stability, ease of law adjustment, and repeatability from one unit to another.

The peak programme meter dates back some 36 years when it was developed to provide a better means of measuring line levels in sound broadcasting than that provided by normal rectifier instruments such as the VU meter. In particular the instrument was given a slow decay and fast attack time to ease reading and lessen eye strain. Early designs were characterized by a very rapid response to transient peaks, but this was later modified since it was found that in practice the ear cannot easily detect the distortion produced by the clipping of very short duration peaks. The final attack time figure decided upon, and which is still standard, was 2.4 milliseconds. Such a response corresponds to a meter reading reaching 80% of peak using a square wave transient lasting 4 milliseconds. The decay time constant used is 1 second, which is a compromise between ease of reading and a response quick enough to record following peaks.

The graduations on the indicating meter were kept small in number and a black scale with white markings used to make for ease of reading. The basic scale division was chosen as 4dB, this being two steps of the standard B.B.C. fader controls. On a standard meter there are basically 7 divisions, with division 4 corresponding to 0dBm on a 600Ω line (0.775V r.m.s. sine wave, 1.095V peak).

The response of the peak programme meter (PPM) is approximately logarithmic and the divisions on the meter are approximately evenly spaced. The extreme divisions (1 to 2, and 6 to 7) represent a greater change than 4dB, namely 6dB. (Earlier meters differed in having all divisions except 1 to 2 equal to 4dB.) The present standard calibration together with the corresponding current in the meter are shown in Table 1.

The meter figures given are for B.B.C. Meter Specification ED1477, the one chosen for the design to be described.

In order to make good use of a fast charge time, the dynamic qualities of the moving-coil meter movement itself must be tightly controlled and considerably faster than that of normal movements. The meter must also be correctly damped to avoid large overshoots—two rather conflicting requirements. Whilst PPM circuits will work with standard meter movements the accuracy will be somewhat impaired unless the correct movement is used. In particular a circuit using a normal meter movement will, when set up on a standard tone level, tend to seriously underestimate short peaks on actual programme material.

Peak detection

In most previous PPMs a normal full-wave rectifier has been used, (Fig. 1), with a centre tapped signal transformer; the charge and discharge time constants being controlled by the two resistors *r* and *R*.

With the advent of integrated circuit operational amplifiers, however, one can now make an accurate peak rectifier without the need to use large voltage swings in order to overcome the forward drop of the rectifier, and the consequent non-linearity at low levels.

The basic circuit of such a peak detector is shown in Fig. 2. On a rising positive input, the output of the op-amp rises positively until the signal fed back to the inverting input of the op-amp via the diode *D* equals the level at the non-inverting input of the op-amp. When the input level falls, the diode *D* ceases to conduct as it becomes reverse biased, and the previous peak is stored on the capacitor *C* until such time as the input rises above the voltage to which the capacitor is charged, when the voltage on the capacitor again follows the input.

In practice the author has modified the basic circuit of Fig. 2 to that of Fig. 3. Apart from the two resistors *r* and *R*, to control the charge and discharge time constants, a transistor has been added to ensure adequate charging current availability. The practical values of the components are $C = 33\mu F$, $r = 75\Omega$, $R = 30k\Omega$. With such a large capacitance the peak charging current through the diode reaches approximately 100mA, which is well above the

Table 1.

PPM reading	Level dBm	Input voltage (peak)	Meter current (mA)
0	—	0	0
1	−14	0.220	0.10
2	−8	0.436	0.22
3	−4	0.690	0.35
4	0	1.095	0.51
5	+4	1.74	0.67
6	+8	2.75	0.80
7	+14	5.50	0.93
f.s.d.	—undefined		1.00

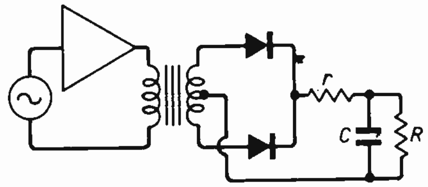


Fig. 1. Conventional PPM using centre-tapped transformer and full-wave rectifier.

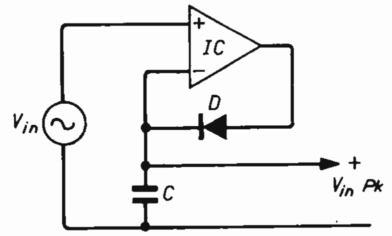


Fig. 2. Peak detecting circuit.

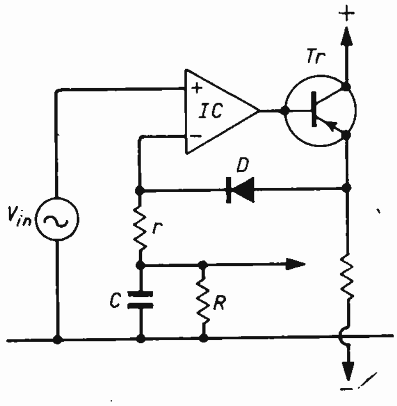


Fig. 3. Peak detecting circuit with time constants added.

capability of a normal i.c. op-amp, hence the additional transistor. (In practice r will be less than 75Ω due to the necessity of allowing for the forward impedance of the diode, and other components in the 'charging' path.)

The peak detector described operates only on positive peaks, whereas in a practical PPM it is necessary to measure positive and negative peaks equally, and to this end it is necessary to either (a) have a similar peak detector of reversed polarity to detect the negative peaks or (b) to have a second similar peak detector and precede it with a unity gain phase inverter.

It was decided to take the second course since it allowed the two positive peak detectors to be combined, sharing a common capacitor, charge and discharge resistors. In this way the highest peak from either detector will automatically be selected.

The unity gain inverter can of course be a centre tapped transformer as in previous PPMs, or else another op-amp connected as a unity gain inverter, as shown in Fig. 4.

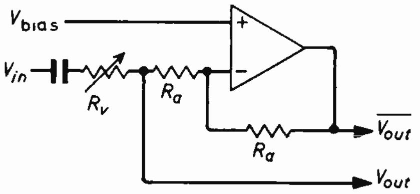


Fig. 4. Unity gain inverting circuit.

Provided that the loading on the two outputs is small, both the a.c. and d.c. levels will be equal except for the phasing. Since the input to the two peak detectors is the non-inverting input of two op-amps the loading is in fact quite low. The difference of d.c. level due to the unequal base supply resistances of the two peak detectors is approximately equal to the typical offsets of the i.cs, and is therefore fairly negligible when compared to the signal levels, i.e. they are less than 10% of the lowest division (1 on the PPM = 0.22V pk). In addition there is a zero set control on the output amplifier which can largely remove the effect from the meter deflection.

Gain adjustment is achieved by the single control R_V for both peak detectors. Whatever the value of R_V, V_{out} and $\overline{V_{out}}$ (Fig. 4) will remain equal and opposite to one another so far as signal excursions are concerned, although at the same d.c. level.

Law corrected output amplifier

The voltage across the peak storage capacitor is applied to a law corrected summing amplifier, whose input resistance (and hence the discharge time constant) will be set by an input resistor R_x to the summing point. The basic principle of this amplifier is illustrated in simplified form in Fig. 5.

The initial gain for voltages close to the bias voltage line (V_{bias}) that is from 0–3 on the PPM scale, is linear, and is set by the ratio R_y/R_x since for small output levels the transistor Tr_1 is reverse biased. When the emitter potential of Tr_1 falls below its bias voltage V_1 the additional feedback resistor R_{f1} is brought into operation in parallel with R_y so that the gain is reduced to

$$\frac{R_y \cdot R_{f1}}{R_x(R_y + R_{f1})}.$$

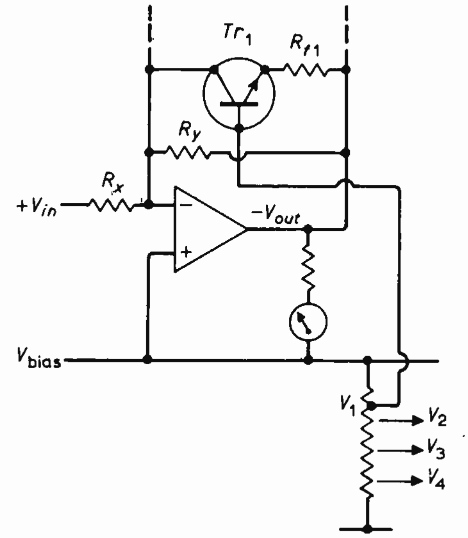


Fig. 5. Use of a transistor in the feedback path to provide law correction of transfer characteristic.

Further feedback resistors R_{f2}-R_{f4} together with transistors Tr_2-Tr_4 each controlled by bias voltages V_2-V_4 respectively, are similarly connected to the amplifier to successively reduce the gain with increasing negative output level. The law corrected amplifier therefore approximates the desired curve of input versus output with a five section linear gain curve as shown in Fig. 6. The choice of feedback resistors and bias voltages is made to get the best match to the actual smooth curve. In practice this was done by graphical methods together with calculation. The values were finally adjusted by trial and error to get the best result, together with the use of standard E24 values. The choice of values possible is almost infinite depending on the choice of break points.

Complete practical circuit

Fig. 7 shows the complete circuit of the peak programme meter based on the circuits described above. It is designed to work with a 1mA meter movement to B.B.C. Specification ED1477.

There are a few items in this circuit not covered in the above circuit descriptions. First, in the feedback network of the law corrected amplifier a diode has been added to prevent any appreciable positive excursion of the amplifier's output on switching on or off. Secondly, a zero set potentiometer is added to this amplifier to take out the combined zero errors of the four op-amps which although small enough to hardly affect the working accuracy is nevertheless rather annoying visually in the absence of an input level.

The zero set potentiometer is the usual value for the type 741 op-amp but is connected in a somewhat different manner. Instead of being connected between the two offset points of the 741 and the negative supply line, a resistor is connected to the slider of the potentiometer and returned instead to the 9.1V bias line. This arrangement allows a much wider range of adjustment than the usual connection, which although adequate to cope with the offset of one 741 op-amp is not sufficient to cope with the combined offset of four op-amps if these should unfortunately be additive.

The d.c. operating level of all stages is determined by the bias supply of +9.1V stabilized by the zener diode D_4 which also supplies the bias chain for the output amplifier's feedback network. This bias chain has an overall adjustment in order that the exact law correction of the completed instrument may be set up, and the tolerances of the various elements allowed for—in particular that of the zener diode stabilized voltage.

The 1mA meter to B.B.C. Specification ED1477, has a resistance of 600Ω ±5% so that with its series resistor of 4.7kΩ (R_{15}), full-scale deflection corresponds to −5.3V with respect to the +9.1-volt bias line. Maximum overdrive of the meter is limited therefore to a little less than the bias line

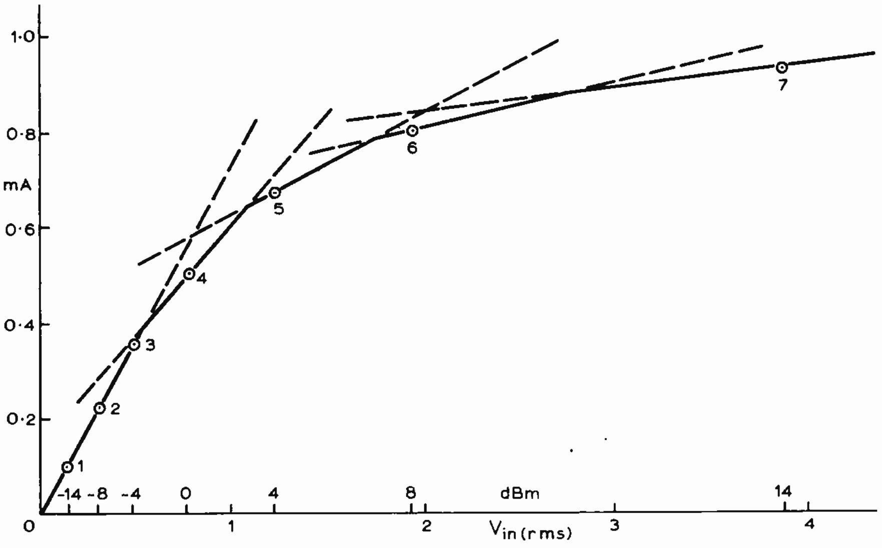


Fig. 6. Low corrected transfer curve approximated by a five section linear characteristic.

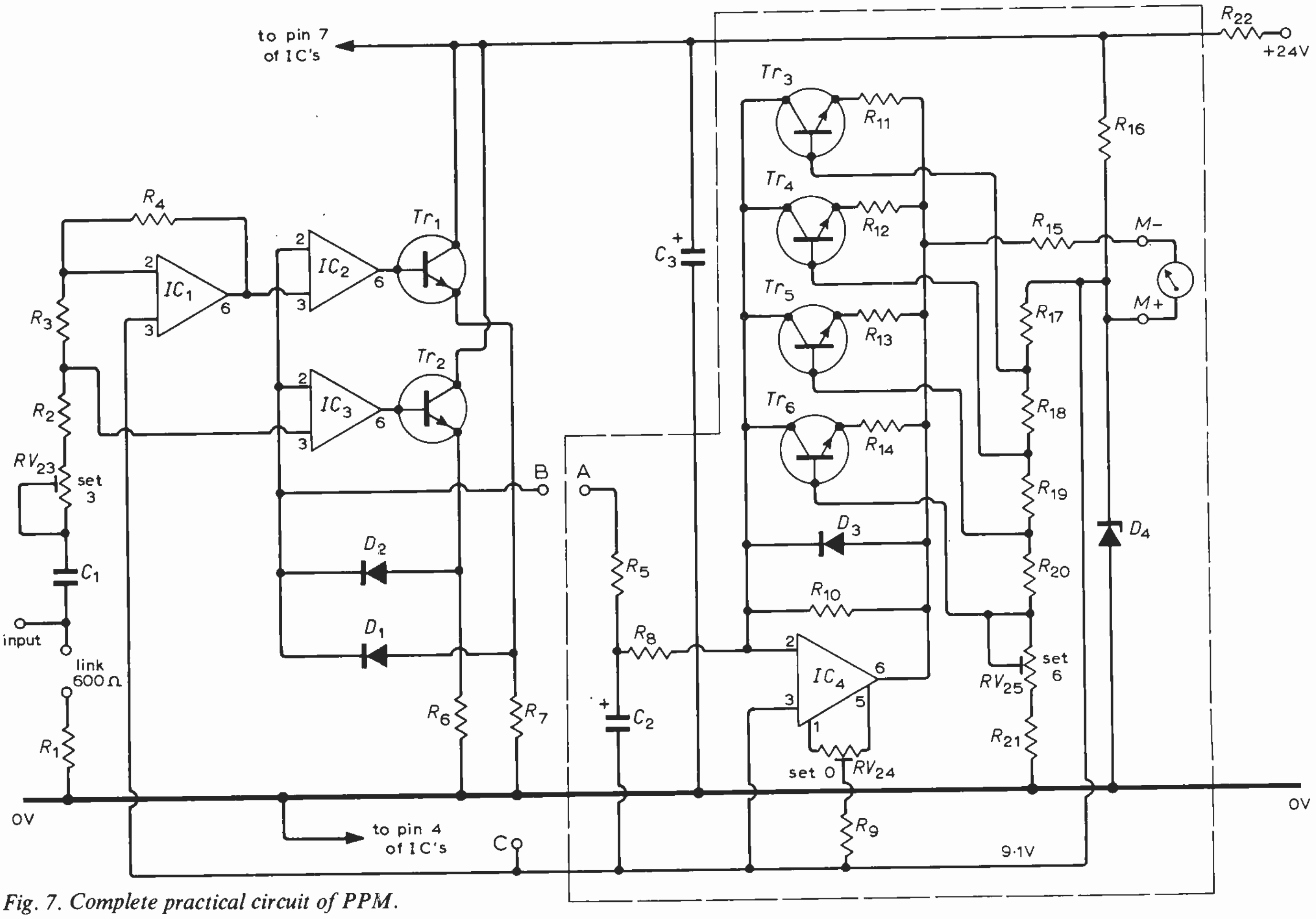


Fig. 7. Complete practical circuit of PPM.

voltage, or approximately some 8V, corresponding to roughly 150% overdrive—a reasonable value for meter protection. The general action of the circuit normally prevents reverse deflection, but in any case the diode in the feedback circuit prevents more than 0.6V being applied to the meter, corresponding to −11% deflection.

Due to the very high peak currents occurring in the peak rectifier circuit, particularly in the collector currents of Tr_1 and Tr_2, some measure of isolation from other equipment sharing the same supply line is necessary. To this end decoupling by R_{22} and C_3 is provided.

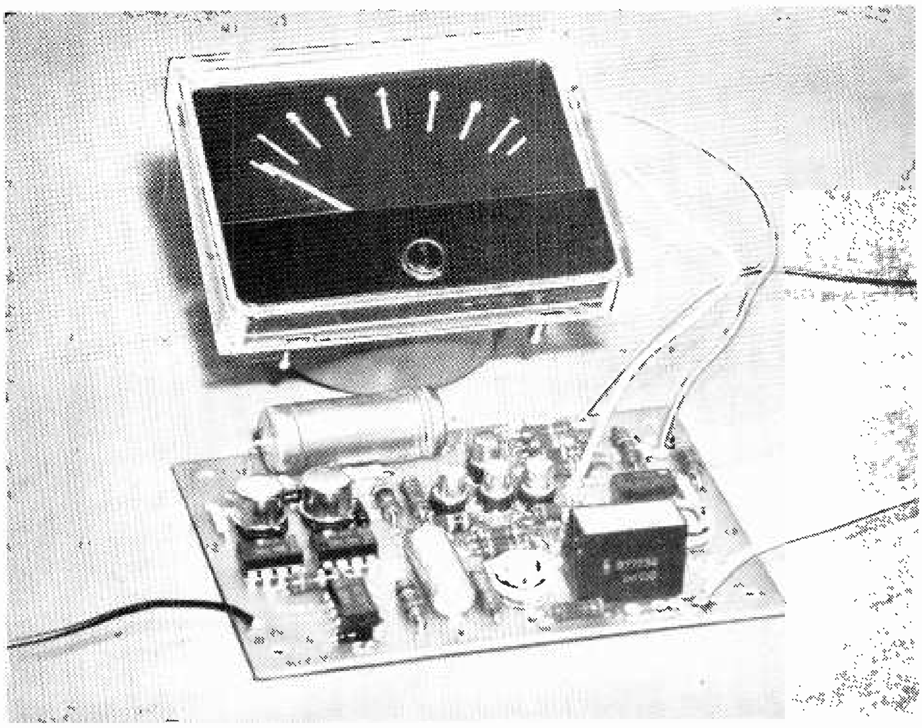
A resistor (R_1) of 620Ω is included so that it can be linked into circuit to give a line terminating impedance of 600Ω instead of the normal line bridging input impedance of around 16kΩ.

Setting-up and performance

The procedure for setting-up the PPM is a simple one. First, with zero input voltage, the zero is set ('Set 0' control) RV_{24}. Next a level corresponding to −4dBm (reading 3 on the PPM scale) or 490mV r.m.s. sine wave, 690mV peak, is applied and the 'Set 3' control (RV_{23}) is adjusted to bring the meter pointer to 3 on the scale. Finally a level of +8dBm, (reading 6 on the PPM scale) or 1.94V r.m.s. sine wave (2.75V peak), is applied to the input and the 'Set 6' control RV_{25} is adjusted to bring the meter pointer to 6 on the scale. The meter is then checked at 0, 1, 2, 3, 4, 5, 6, 7, and f.s.d. points as listed in Table 1, and any small adjustment made to the 'Set' 0, 3, and 6 controls to minimize the spread of errors. Having completed the sequence of adjustments the meter should read within 0.5dB at 1kHz at all scale marks, although f.s.d. is as stated in Table 1 undefined (it will usually correspond to around 5.3V r.m.s. sine wave).

Performance versus temperature. The PPM has very little variation with temperature. A 30°C rise in temperature (from 17°C) gave only about 10μA change in meter current at any point of the scale, i.e. about 1% of f.s.d.

Performance versus frequency. As shown in Fig. 8 there is a slight droop in the upper frequency range, and this is due to the limited slew rate capability of the 741 op-amp in the peak detectors. Amplifiers



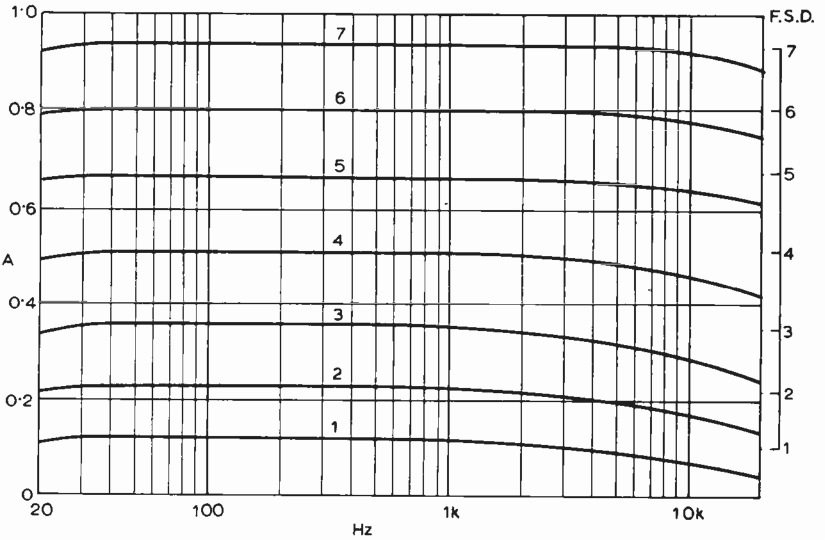
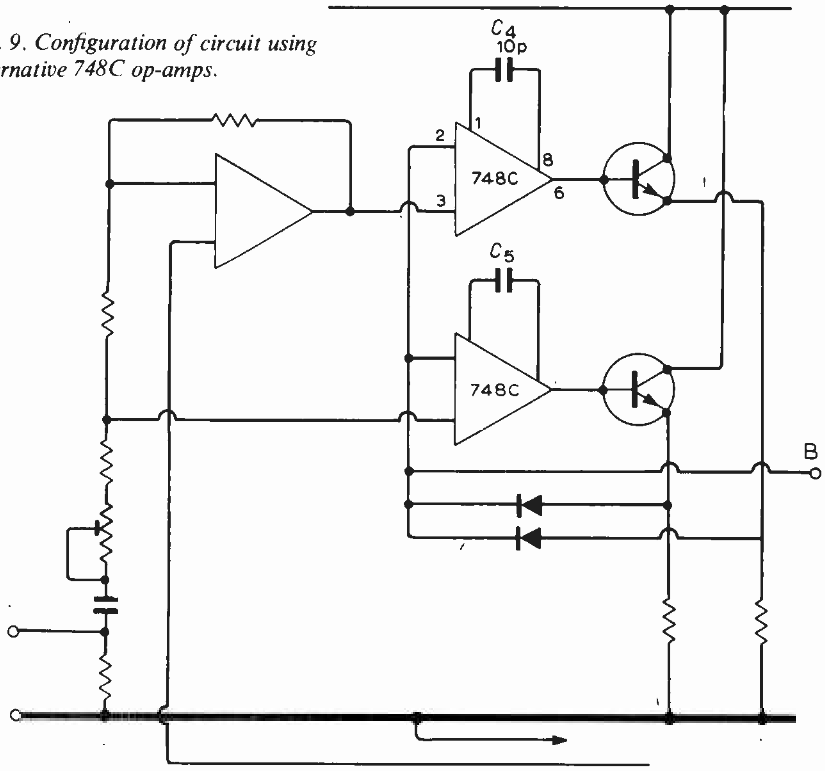
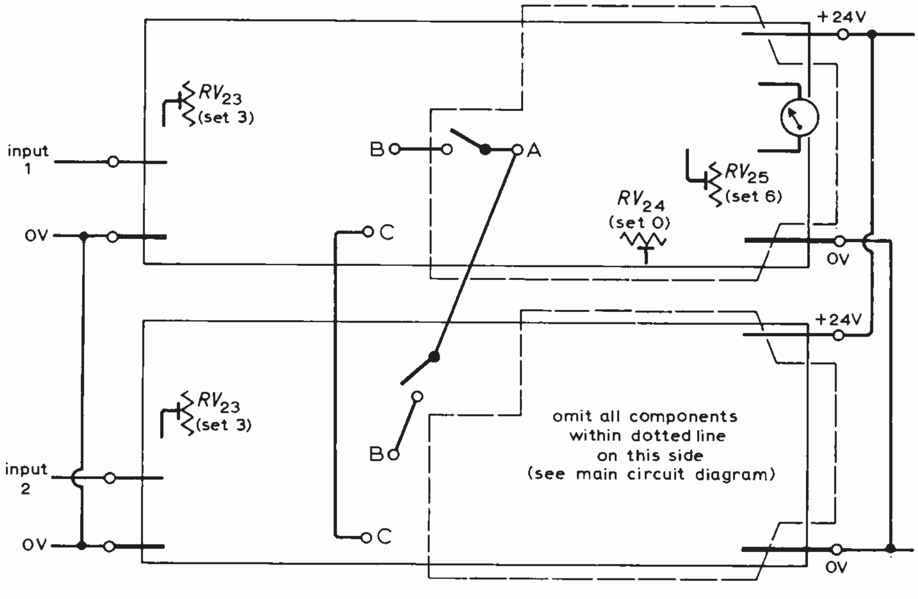


Fig. 8. Frequency response of prototype PPM.

Fig. 9. Configuration of circuit using alternative 748C op-amps.





omit all components within dotted line on this side (see main circuit diagram)

Fig. 10. Outline of printed circuit panel for mono or stereo.

having a higher slew rate have been tested and do remove this limitation in the audio range. The 748 op-amp has a higher speed performance than the 741 but uses external compensation; this allows the response to be tailored to suit any particular need. Fig. 9 shows how two 748 op-amps may be used for IC_2 and IC_3, together with appropriate extra components to obtain a flat frequency response over the whole audio band. There is still a slight fall off at 20kHz but this is greatly reduced as compared to the 741 op-amp.

In practice does this h.f. droop matter? The author would argue that for the monitoring of practical speech and music levels it does not matter to any noticeable extent. This is because of two factors. First, there is the attack response time of 2.5ms used in the circuit, meaning that a level must last for several milliseconds to register near to its true peak level, and secondly, in general, frequencies above about 5kHz do not exist at as high a level as the lower frequencies, and these lower frequencies therefore largely determine the peak amplitude at any time.

Performance versus supply voltage. Over the range of 16 to 30V there is little visible change of reading at any level of input. The circuit is designed for operation from a nominal 24-volt supply. Supply current is somewhat dependent on input level, and is typically 14mA at zero input, rises fairly rapidly as input is applied, and reaches 20mA at full scale. There will be some variation from unit to unit but at 24V the current should remain in the limits 13–22mA. The current demand is also dependent on supply voltage being lowest at 16V and highest at 30V. An absolute maximum supply voltage of 36V should never be exceeded.

Connections for stereo use with a single common meter

For economic or space reasons, it may be desired to use two PPM circuits with a common meter, and the printed circuits were designed with this in mind as an option. The method of interconnection is shown in Fig. 10 where two input circuits up to point *B* are used, with only one output circuit from point *A* onwards. The bias supply is made common to both boards by linking points *C* together.

To set up the meters in this method of connection the zero is first set at nil input level (to both inputs), 'Set 0' control (RV_2).

Next inputs of −4dBm are connected to each input in turn and the appropriate 'Set 3' control (RV_{23}) for that channel is set to give a reading of 3 on the PPM. Finally the 'Set 6' control is set to give a reading of 6 from either input at a level of +8dBm.

For the setting of the 'Set 3' and 'Set 6' controls both inputs may be connected in parallel and the switches shown in Fig. 10 operated to select the channel to be set up.

The dotted lines in Fig. 7 show the section of circuit omitted on one board and correspond to the dotted lines in Fig. 10.

Acknowledgements

The author wishes to express his grateful thanks to the B.B.C. Engineering Depart-

ment and in particular to Mr. A. E. Tolladay, for considerable help and encouragement, also to Ernest Turner Electrical Instruments Ltd. for their help in the project.

Constructional appendix

The circuit is built on a printed circuit board $3\frac{1}{2} \times 3\frac{1}{2}$ inches in size with mounting centres of 3.1×2.1 inches (6BA). The board, which is suitable for either the circuit with 741s in all stages or the higher speed circuit with 748s in the peak rectification stages, is shown in prototype form in the photograph. Layout of production boards will differ slightly but all component positions are silk screened onto the component side of the board.

It is essential that the charge storage capacitor C_2 be a low leakage type, hence the specification of a solid dielectric tantalum type. An alternative is the solid dielectric aluminium capacitor such as Mullard type 121 15339 (33µF 16V) or 121 16339 (33µF 25V). However, it should be remembered that these are of 20% selection tolerance, and it may be necessary to select one to the necessary tolerance of 10%. In general normal aluminium electrolytics are not suitable, due to their high leakage (especially at elevated temperature) and very wide tolerance, even of the higher quality type (e.g. Mullard C428 is −10 +50%).

No special techniques are used in the construction and the only precautions needed are to ensure correct insertion of the 8-pin dual-in-line op-amp packages, and to avoid shorts on the board due to careless soldering (a miniature soldering iron is, these days, essential for printed circuit work). Mounting pads are used under the 6 transistors but are not absolutely essential. Connections are by 14–0076 p.v.c. covered leads as shown in the photograph.

All component parts in kit form together with Ernest Turner PPM meters type 642 are available from Key Electronics, P.O. Box No. 7, Bournemouth, BH7 7BS, Hants.

Components list

Resistors

R_1	620	R_{13}	56k
R_2	2.2k	R_{14}	15k
R_3, R_4	10k	R_{15}	4.7k
R_5	68	R_{17}	1.2k
R_8	30k	R_{18}	620
R_{10}	160k	R_{19}	560
R_{11}	220k	R_{20}	270
R_{12}	120k	R_{21}*	

All the above are 2% metal oxide or metal film (e.g. Welwyn MR5 or Electrosil TR5).

*Resistor R_{21} will normally be a wire link. (For use only where a higher reference line voltage than 9.1V is to be used.)

R_6, R_7	22k	R_{16}	2.2k
R_9	220k	R_{22}	47

All the above are $\frac{1}{8}$W 5% carbon film (e.g. Iskra UPM033 or Mullard CR25).

Capacitors

C_1	1µF, 100V poly (15mm mounting centres)
C_2	33µF, ±10%, 20V solid dielectric tantalum
C_3	220µF, 35V, aluminium electrolytic.
C_4, C_5	10pF, ceramic tube, disc or poly.

Transistors

Tr_1, Tr_2	BFY52 or 2N2219.
Tr_3 to Tr_6	BC109.
D_1, D_2	OA200, 1S920.
D_3	1S44, 1N914, 1N916.
D_4	BZY88-C9V1 (9.1V, ±5%, 400mW).
IC_1	741C (8 pin d.i.l.).
IC_2, IC_3	741C (8 pin d.i.l.) or 748C for high-speed version.
IC_4	741C (8 pin d.i.l.).

N.B. The TO-99 versions (multi-lead TO-5), of the 741 and 748 may also be used since they have the same lead layout and are easily arranged in d.i.l. lead configuration. Jermyn Industries Ltd., type MON-8L mounting pad may be used to achieve this end.

Preset potentiometers

RV_{23}, RV_{24} 10k ±20% RV_{25} 5k ±20%

Open cermet potentiometers (R.S. Components or A.B. Electronic Components).

Semi-sealed type Morganite 81E may also be fitted (also from R.S. Components).

Announcements

Information Retrieval is the title of a course of six lectures to be held at Twickenham College of Technology on Monday evenings at 19.00 commencing 6th November. Details from The Principal, Twickenham College of Technology, Egerton Road, Twickenham, Middlesex TW2 7SJ. Fee £3.75.

Pickup arm and turntable parts. Longdendale Technological Products, suppliers of parts for the pickup arm and turntable designs published in the October and November 1971 issues, have moved to Wood End Industrial Estate, Manchester Road, Mossley, Manchester.

Arrow Electronics Ltd, 7 Coptfold Road, Brentwood, Essex, has been formed to provide a retail mail order distribution service for a range of components from opto-electronics to $\frac{1}{4}$W carbon resistors; temperature controlled soldering irons to aluminium boxes; test instruments to the latest double-wound toroid chokes.

Television Systems and Research Ltd, 63 Woodside Road, Amersham, Bucks, formed to acquire the business and assets of the Top Rank Television Division of Rank Audio Visual Ltd, have been appointed by TeleMation Ltd to be exclusive distributors in the U.K. and Ireland of the TeleMation range of closed circuit TV equipment.

Marconi Space and Defence Systems Ltd is to supply a **cockpit procedures trainer** to Flight Safety Inc., the professional pilot training organization in America, acting on behalf of Aeroformation. The trainer, to be completed by late 1973, will be installed in a new multi-million dollar Aeroformation Training Centre in Toulouse, Blagnac, France.

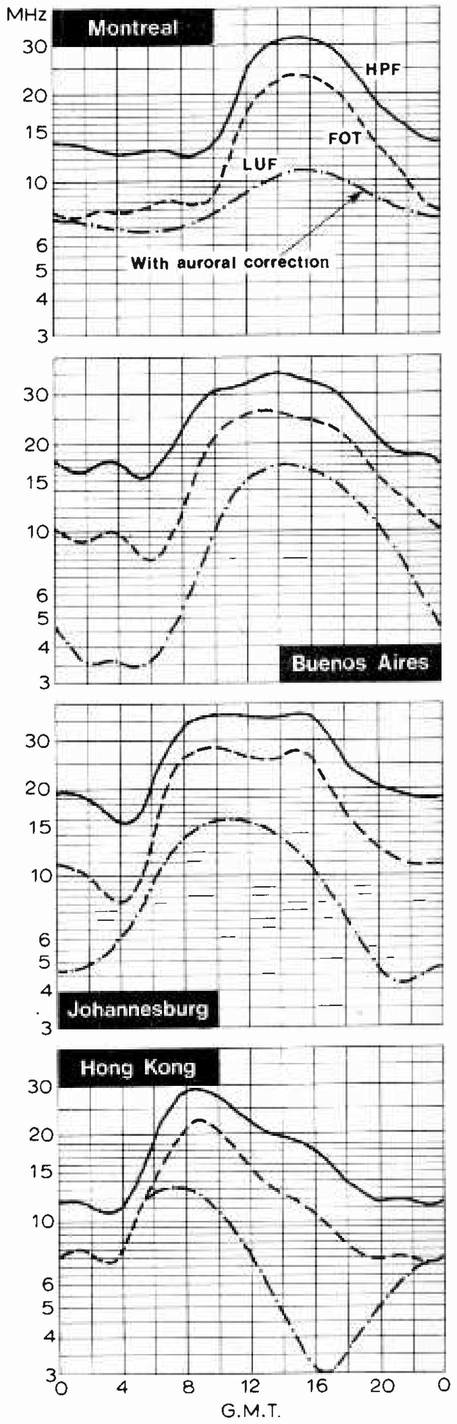
Marconi Communications Systems Ltd and Amalgamated Wireless (Australasia) Ltd are jointly to supply equipment for the Australian Broadcasting Commission's new **colour television service.** Scheduled to be operational by March 1975, Marconi are supplying four of their Mark VIII automatic colour cameras and ancillary equipment with an outside broadcast vehicle.

Consolidated Fisheries Ltd., Grimsby, are to fit their entire fleet of 15 distant-water trawlers with the new, world wide, **Redifon Omega Navigator.**

H.F. Predictions — November

Solar activity is still not declining as rapidly as expected. The past three years have shown a check in decline during each September which has been maintained. This could mean that the current sunspot cycle will be two years longer than the eleven year average giving a minimum in 1975/6.

With this relatively high activity the 26-MHz broadcast and 28-MHz amateur bands should be open between 08.00 and 16.00 GMT throughout the month to South Africa. These two bands will also be usable for South America but not so consistently and to North America only for very short periods, if at all.



Letters to the Editor

The Editor does not necessarily endorse opinions expressed by his correspondents

Low-noise audio amplifiers

I would like to thank Mr Linsley Hood for raising in his letter in the August issue (p. 389) several interesting points arising from my article on low-noise amplifiers (May issue p. 233).

The first part of my article considered the noise performance of the two feedback configurations, assuming ideal amplifiers, in order to determine which offered the theoretical best signal-to-noise ratio for a given set of input parameters. In fact optimum performance is achieved when a combination of shunt and series feedback is used to establish the required input impedance rather than with shunt or series resistors. Having decided this, the appropriate type of transistor is chosen for optimum noise figure – rather than the other way round.

The Motorola 2N5089 certainly has a very high optimum source resistance and therefore by implication a very high common-emitter input resistance, but this is not necessary, or indeed desirable, for a virtual-earth configuration. Mr Linsley Hood has pointed out in the Appendix 1 to his article "Modular Pre-amplifier Design" (July 1969, p. 306) that there is essentially no difference between detecting the signal current through, or voltage across, the input resistor. In the one case we wish to maximize the signal current with a low-impedance amplifier.

In Fig. 1, the input signal is represented by I_1 in parallel with R_1 (the input arm) and the feedback signal by I_2 and R_2. The amplifier is considered as a negative transfer impedance, $Z_t = -V_o/i_{in}$, which should be very much greater than R_2 for stable gain. In the tradition of good current amplifiers, it should have a low input impedance (i.e. common-base rather than common-emitter) so that available current is not shunted by R_1 and R_2, and hence $i_{in} = (I_1 - I_2)$. In audio circuits with high-gain operational amplifiers this is not really important, but at v.h.f. considerable improvement in performance can be achieved. With current amplifiers it is best to consider the summing of all noise and signal currents at the input node, in the same way that one would sum voltage sources with high-impedance amplifiers in the series circuit illustrated in Fig. 2.

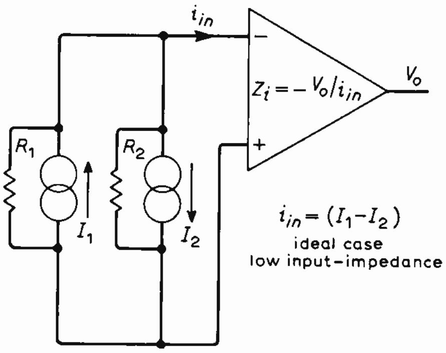


Fig. 1. Current sources in shunt circuit.

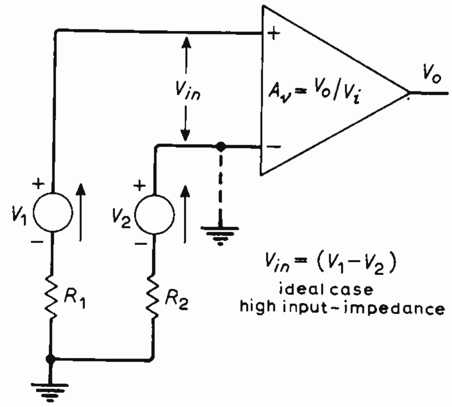


Fig. 2. Voltage sources in series circuit, the dual of Fig. 1.

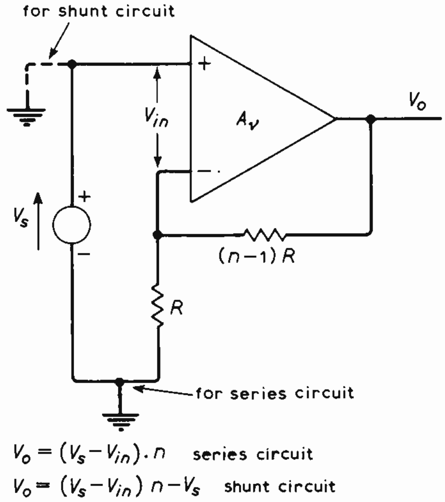


Fig. 3. Operational amplifier feedback: shunt and series circuits obtained by moving the earth; expressions for V_o therefore differ by V_s.

I am not sure what Mr Linsley Hood means by "transfer non-linearities between the inverting and non-inverting inputs" in the context of distortion. For the circuit of Fig. 2, the open-loop distortion characteristics of the amplifier can be measured by applying the appropriate input signals. (Normally the drive conditions are simplified by earthing the inverting input, e.g. the emitter of the input transistor.) When the loop is closed the distortion will be reduced in the usual way by the factor $(1+A\beta)$. As the error signal V_{in} acting in series with $V_{feedback}$ is made proportionally smaller as the feedback is increased, the distortion can be reduced indefinitely, (when A_v is infinite, V_{in} is zero and therefore distortion is also zero). As the feedback is increased in the shunt-feedback arrangement, Fig. 1, the error signal i_{in} becomes proportionally smaller, or, looked at another way, the shunting effect of the non-linear transfer-impedance on the feedback network is reduced.

The shunt-feedback circuit may be at a slight advantage since current driving at the input is an inherently more linear process in bipolar transistors, but in a well-designed amplifier the large signal stage (not the input stage) should cause most distortion. The only real problem with the series feedback circuit occurs when large and almost equal signals are applied to inverting and non-inverting inputs and effects such as base-width modulation may take place. This could be accounted for by applying the necessary signals in the open-loop distortion test.

Fig. 3 shows the arrangement of feedback in an operational amplifier and illustrates that the only difference between shunt and series connections is the position of the earth. Both expressions for V_o include a term in V_{in} which can be arbitrarily reduced as the loop gain is increased.

In conclusion there are one or two corrections I would like to make to the text of my article. The units of the vertical scales of Figs 2(a) and (c) should be $nV/\sqrt{Hz}$. The distortion figure quoted for Fig. 8 at the end of the example is the open-loop measurement. The reference 12 in Appendix 2 should have been 13 and referred to "Characteristics and Limitations of Transistors" by Thornton *et al.*, S.E.E.C. Vol. 4, chapter 4, pp. 134–177 (Wiley 1966), and "Vacuum Tube Amplifiers" by Valley and Wallman, pp. 496–501 (M.I.T. Radiation Laboratory Series, Dover 1965)—which somehow got lost in the preparation.

H. P. Walker,
South Queensferry,
W. Lothian.

Regulated power supplies

Anyone using small power supplies with circuits such as audio pre-amplifiers, f.m. tuners and stereo decoders will have discovered the importance of minimum output ripple and noise voltages, as well as good output regulation and temperature stability. To achieve this it is becoming common to use a feedback regulator circuit[1] using operational amplifiers such as the 741.

Such circuits work extremely well, but their performance is ultimately limited by

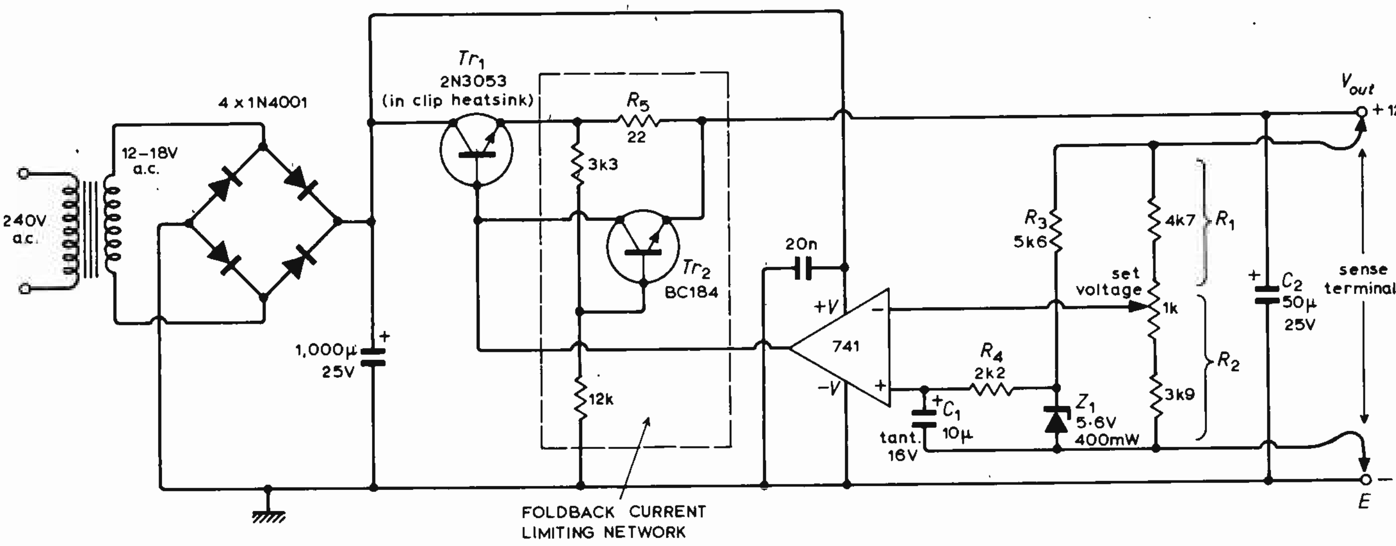


Fig. 1. 12-V regulated power supply for use with unregulated supplies of less than 36 V.

the reference voltage used, usually a zener diode. Unfortunately this is often fed from the unregulated supply. If the a.c. zener resistance is r_z ($\sim 30\Omega$) and it is fed through a resistor R_f ($\sim 1\text{k}\Omega$), then the input ripple is reduced by the factor $r_z/(R_f+r_z) = 0.029$ and no amount of feedback can further reduce the output ripple.

Most designers attack this problem by using a pre-regulated supply to feed the zener, and end up building two regulators instead of one. This approach could lead to an infinite series of pre-regulated pre-regulators in the pursuit of less ripple.

However, a better and simpler method of improving performance is to put the reference zener inside the feedback loop by feeding it from the output, which, if the regulator is working well, will be well stabilized. Taking as an example the 12V 150mA regulator in Fig. 1, analysis of the loop shows that, provided $r_z/(R_3+r_z) \ll R_2/(R_1+R_2)$, and the loop gain is large, the regulator behaves as if Z_1 were a ripple free reference voltage.

Noise, mainly of high frequency, from Z_1 is filtered by R_4 and C_1, which must be a tantalum capacitor. The 50μF electrolytic, C_2, further reduces output noise, especially at high frequencies where the regulator loop gain falls off. The regulator incorporates foldback current limiting, set by R_5. The high supply voltage rejection ratio of the 741 (>70 dB) allows us to connect the positive supply terminal on the op-amp to the unregulated supply line, provided this is at less than 36 volts above the negative rail. Where the unregulated supply voltage is greater than this, regulated supplies giving up to 36 volts can be made, with no loss of performance, by connecting the op-amp $+V$ terminal to the regulated output, and by using an extra zener, Z_2, to voltage shift the output of the 741 (Fig. 2). Resistor R_6 should be chosen to give the required 5mA feed to the zener. Those who are tempted to replace Z_2 by a voltage shifting transistor, having gain, are likely to be rewarded with a megahertz oscillator!

The power supply in Fig. 1 is suitable for use with the Nelson-Jones tuner (*Wireless World* April, May 1971, April 1972) and the RCA3090Q stereo decoder (*Wireless World* August 1971). A number have been constructed for this purpose with excellent results.

Typical performance of this supply is:

output voltage	12V
max. regulated current	150mA
short-circuit current	70mA
output ripple ('hum')	<40μV r.m.s.
output noise	<20μV r.m.s.
d.c. output impedance	<0.01Ω
input ripple rejection ratio	1.7×10^5.

The basic circuit is easily modified to give higher output currents and/or negative regulated supplies.

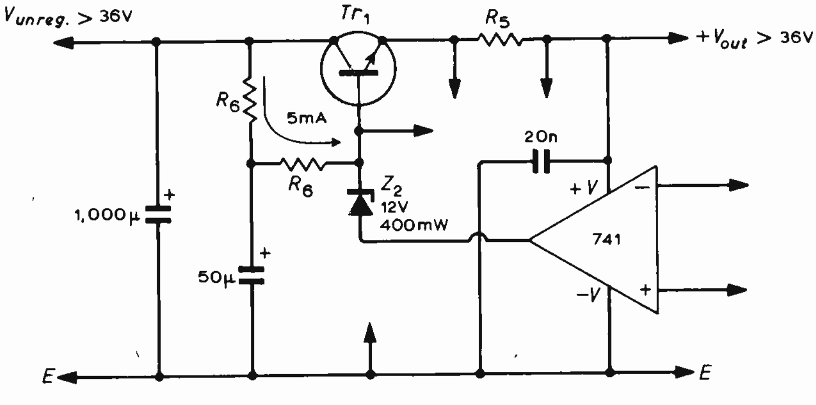


Fig. 2. Part of the regulator in Fig. 1 showing modifications for unregulated supplies of over 36 V.

To repeat my main point: placing the reference zener inside the feedback loop of a regulated power supply can greatly reduce the output ripple.

M. L. G. Oldfield,
Dept. of Engineering Science,
University of Oxford.

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1. Towers, T. D., "Elements of Linear Microcircuits: 9. Voltage Regulators." *Wireless World* Vol. 77, p. 342 (July 1971).
2. Dobkin, R. C., "High Stability Regulators" National Semiconductor Linear Brief 15 (Jan. 1971).

High-load transistor voltage amplifiers

Some well-known transistor voltage amplifiers for audio use have collector load impedances which are made artificially high by bootstrapping or some other circuit trick. One reason given for adopting this technique is distortion-reduction, which is said to be brought about as follows. Most of the distortion (it is claimed) arises from the non-linearity of the relationship between base-emitter voltage and collector current; i.e., non-linearity of the mutual conductance. If the stage gain is made very high, the input signal can be reduced. This minimizes the extent to which the input signal traverses the non-linear characteristic and so reduces distortion.

This argument would be convincing if the amplifiers in question used only one transistor. But there is invariably a second transistor: either a bootstrap follower to enhance the load of the first or a straightforward emitter-follower output stage to reduce the output impedance to a usable level. These additional transistors themselves produce distortion.

Common sense shows that reduction of input-voltage swing is not the reason for observed differences in performance between a conventional common-emitter amplifier (Fig. 1) and a high-load arrangement such as Fig. 2. If the two amplifiers have equal gains and if the d.c. operating conditions for the input stage are the same then for equal outputs the input voltages are also equal, so any distortion due to non-linearity of mutual conductance must be the same in each input stage. Any differences in distortion must then be accounted for in some other way.

The component values shown in Figs 1 and 2 were chosen so as to equalize the collector currents of the input transistors at about 60μA. Under these conditions the common-emitter amplifier had a higher gain than the bootstrapped amplifier (13,000 compared with 2200). This is in accordance with theory: the gain of the common-emitter amplifier approximates to $g_{m1}.h_{fe2}.R_L$, while that of the bootstrapped amplifier approximates to $g_{m1}.h_{oe1}$, and with practical values for the variables the ratio of these gains is around 10. When the gain of the common-emitter amplifier was reduced (by adjusting R_E to 1800 ohms) to be the same as that of the bootstrapped amplifier the distortion for 1mV r.m.s. input was 0.8% for the common-emitter amplifier, compared with 1.6% for the bootstrapped amplifier. (These measurements were taken using the same two transistors in each circuit.)

Fig. 1

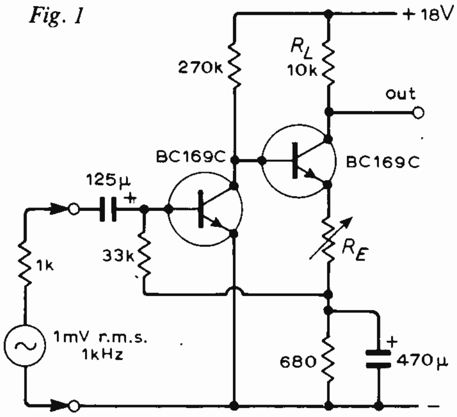
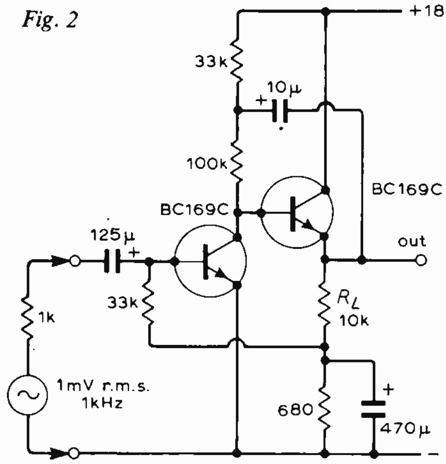
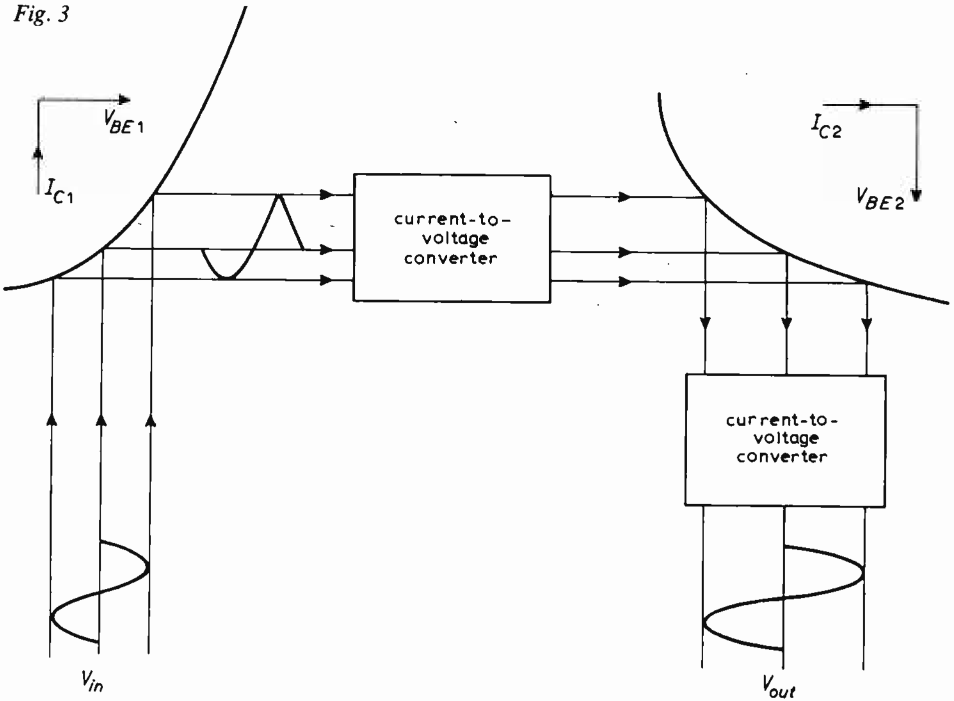


Fig. 2



It is clear that the method of equalizing the gains must have reduced distortion in the common-emitter amplifier, since it consisted of introducing some local negative feedback. A further test showed that it is not quite as simple as that. When R_E was transferred to the emitter of the input transistor, and again set to equalize the gains, the common-emitter distortion rose to 3%. From this it follows that the relative levels of signal at the inputs of the two transistors are an important factor, and once again this is to be expected from theory.

Fig. 3



A two-stage amplifier with an inverting first stage contains a built-in distortion-cancelling mechanism. The curvature of the characteristic of the second stage is in the right sense to straighten out the effects of the overall transfer characteristic. This is shown qualitatively in Fig. 3, where the "current-to-voltage converters" are put in to represent the effects of the collector loads. It is apparent that the amount of distortion-cancellation actually obtained depends on the signal amplitudes and their relations to the working points of the transistors. A further variable is the current-voltage converters themselves, here tacitly assumed to be linear but not so in practice, since the load seen by the first transistor depends on the (non-linear) characteristics of the second. In high-load amplifiers which use an active load, such as an f.e.t., there are further opportunities for distortion-cancellation, since this load, too, is non-linear.

One thing apparent from Fig. 3 is that the overall distortion changes very much as the working point of the second transistor is changed. Designers tend to select the operating conditions of the second transistor on considerations of what load is to be coupled to the output, current economy, and so on. These do not necessarily lead to minimum distortion.

G. W. Short,
Croydon,
Surrey.

Noise—white, pink, red

The letter from Mr R. N. Baldock in the October issue (p. 476) raises a number of interesting points. It has long been a common practice in English to enrich the language by taking expressions from one context and using them in a totally different connection. For example, the number of non-cricketers who have been 'bowled middle wicket' must be vast, as also the number of non-golfers who have been 'stymied'.

When we come to the terms referred to in Mr Baldock's letter, their main use has been to give a convenient abbreviation as well as a rough description. To the purist there may be some difficulty. Thus light having a smooth continuous spectrum with equal energy per wavelength (not per cycle) appears white whilst light having equal energy per cycle appears definitely bluish. The former spectrum is merely one of the many ways of producing white light, yet it is the only one we have in mind in referring to the analogous white noise, a term which has long been accepted by international authorities.

I coined the term 'pink noise' in 1949 to describe noise having equal energy per octave and produced from white noise by an appropriate equalizer[1] although, of course, it was not permissible to print the term at the time. Now, to the colour specialist such an optical spectrum would indeed be described as relatively pink, but he might well add that a similar shade could be obtained by merely adding a red line spectrum to a white light. Such, of course, would not be permissible in sound where a corresponding summation of the stimulus does not take place; so pink noise is an accurate description and one which has recently received the accolade of acceptance by the I.E.C. and B.S.I.

Miserere mei! I must also plead guilty to having used the term 'red noise' in 1968[2] for $1/f$ noise, and in spite of Mr Baldock's misgivings I stand by it. There is no doubt that if white light were passed through a transparency having the corresponding characteristic, the resulting light would be described as red. I know that the colour red could also be obtained by means of a line spectrum corresponding in the case of sound to a low-frequency pure tone, but in common parlance the additional term 'noise' indicates a wide-band spectrum, unless otherwise specified; and so the term 'red noise' is justified as being redder than pink noise.

The use of these descriptive terms is therefore not terminologically unambiguous, but the fact that we have stretched the optical bandwidth to fit the acoustical one does not really seem to matter. The main point is that the meaning should be clear to the reader so that information is really being conveyed.

As to the further use of these terms, I have known noise from an aperture-corrected monochrome television camera described as 'blue' as the spectrum rises faster than equal energy per cycle; this seems quite a justifiable use of the term. When, however, we get to 'muddy brown with some bluish lines' there is no doubt that while the expression conveys something, it is much more vague. If, in a more humorous vein, we go one further and take some modern pop music, this seems to consist largely of bass and treble, i.e. red and blue components. Is this why this music is sometimes described as 'purple'?

In conclusion, the descriptive terms used seriously so far serve a definite and useful purpose; it is up to authors and editors to see that this continues.

H. D. Harwood,
B.B.C. Research Dept.,
Tadworth,
Surrey.

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1. Harwood, H. D. and Shorter, D. E. L., "A High-Level Noise Source for the Audio-Frequency Band." *Jour. Sci. Inst.* Vol. 27, No. 9, Sept. 1950 p. 250.
2. Harwood, H. D., "Developments in Microphones." *Wireless World*, April 1968 p. 58.

Synchronous detector

Stimulated by Mr G. Wareham's and Mr P. Hawker's articles (August and September issues) I would like to report my personal experience with long-distance a.m. reception using a synchronous phase-locked detector.

During a stay as a visiting professor at the University of Aarhus, Denmark (1971/72) my family and I desired to listen to the Austrian home transmissions on medium-waves and to the short-wave service (distance approx. 1000 miles). After some unsuccessful attempts I could provide adequate reception by buying a relatively expensive receiver – definitely distinct from ordinary portables – and adding a synchronous demodulator after some modifications in the receiver's r.f. section. To reduce the response to spurious signals (short-wave whistles in the m.w. band with a long aerial) I replaced the bipolar mixer transistor by a double balanced modulator (Motorola MC 1596) and introduced some negative feedback into the r.f. stage in order to improve its large-signal capability. These measures allowed whistle-free reception, however suffering quite often from interference, noise and propagation disturbance (selective fading). Here the synchronous detector (consisting of another balanced modulator driven by a 2mV, 455kHz i.f. signal and its phase-coherent carrier extracted by a phase-locked loop of 5Hz bandwidth – Signetics NE561B) improved the reception to such an extent that it could also be accepted by the normal radio listener. The post-detector low-pass filter increased the selectivity, the signal-to-noise ratio was audibly better and in case of periodical selective fading in particular on short-wave a speech signal remained intelligible in contrast to the simultaneously operating envelope detector still used for a.g.c.

H. Leopold,
University of Graz,
Austria.

Doppler effect

On reading in print on p. 388 of your August issue my reply to Mr P. J. Unwin I realized that its first paragraph might easily appear to contradict Part 2 of my article on Doppler effect. Now that Mr J. E. Foggitt has shown in the following issue (p. 423) that my fear was justified I am glad to have the opportunity to explain that my statement that "the Doppler question does not arise" referred not, of course, to electromagnetic waves in space but to the particular transmission-line analogy put forward by Mr Unwin, in reference to which he said he was unaware of any Doppler difficulties in combining signals for simultaneous transmission down a line.

I am also glad to be able to say that my appeal for experimental evidence of Doppler distortion was abundantly answered by Mr James Moir (whose name was foremost in my mind as a likely source of hard experimental facts on the subject) with a copy of his article "Doppler Distortion in Loudspeakers" in *Hi-Fi News*, January 1967. His experiments were carried out in the most thorough and convincing manner, and led to the conclusion "This suggests that in practice Doppler distortion is a more serious problem than straight intermodulation distortion, even with large speakers". A reading of the article leaves little scope for any who question the existence of Doppler distortion.

The idea of negative Doppler distortion introduced at the receiving end, suggested by Mr Foggitt, is a fascinating one, but not likely to be significant in practice, as is confirmed by the results just cited. Neutralizing of loudspeaker distortion by the low-frequency movement of the microphone diaphragm used for measuring the distortion could take place only if those movements were identical in amplitude and phase with those of the speaker. Normally they would be very much smaller in amplitude and there would be a phase lag depending on the distance of the microphone and the frequency. At a typical listening distance, say 10ft, at 50Hz the lag would be about 180°, so any Doppler distortion introduced thereby would be positive. The same principles apply to the recording situation described by Mr Foggitt.

In answer to his points about multiple diaphragms, I am happy again to rely on the authority of Mr Moir, who confirms that this technique is the best solution to the Doppler problem in loudspeakers.

The conditions in headphone listening are not comparable, so do not permit the conclusion drawn by Mr Foggitt. On the contrary, they do approximate to those he wrongly assumed to apply in the case of loudspeaker and microphone, since the low-frequency amplitude of eardrum vibration might well be appreciable in comparison with those of the headphone diaphragm. But even without any cancellation introduced thus, the Doppler distortion, being proportional to the amplitude of diaphragm movement, would be very small compared with that from a single-diaphragm loudspeaker.

Cathode Ray.

Servicing help needed

The British Talking Book Service for the Blind provides tape reproducers for the use of the blind and a library service of recorded books. The books are recorded by a voluntary panel of readers and the reproducers are kept working by service volunteers. There are about 34,500 reproducers throughout the country and some 2000 volunteers.

Some of your readers already give their services to this worthwhile cause but more would be very welcome, especially in the Metropolitan London area. Most faults are simple and a volunteer may spend 5 minutes repairing the machine and a further half hour talking or listening to someone who is pleased just to hear a new voice. The gratitude shown by the blind folk is somewhat embarrassing but these books mean a lot to them.

If any reader would like to volunteer please write or telephone Mrs Howes, the Service Department, British Talking Book Service for the Blind, Mount Pleasant, Alperton, Wembley, Middlesex, HA0 1BR. (Tel: 01-902-2161.)

A. J. Smale,
A service volunteer.

Cassettes and cartridges

A footnote to the article on "The Domestic Video Recorder" (September *Wireless World*) gives a rather inelegant definition of a "cassette".

The European Broadcasting Union uses the term "cassette" to denote a film or tape magazine containing two spools, whereas the term "cartridge" denotes a magazine having only one spool.

L. F. Odell,
Visionhire Ltd,
New Malden,
Surrey.

Experiments with Operational Amplifiers

6. Straight line approximated non-linear response

by *G. B. Clayton*, B.Sc., F.Inst.P.

Straight line approximated non-linear functions can be generated by using an operational amplifier to sum a series of currents, the current sums being used to define the slopes of the linear approximations. The magnitudes of the current components in the sum are determined by resistor values, while the break points at which changes of slope occur are set by a reference voltage, diode and resistive dividers.

Graphs illustrating the action of the Fig. 6.1 circuit are given in Fig. 6.2.

An oscilloscope display of the circuit response is obtained by applying a low-frequency sinusoidal signal to the input. The sinusoidal signal is used to give the horizontal deflection and the output of the amplifier gives the vertical deflection for the display.

Typical waveforms obtained with the circuit are shown in Fig. 6.3. In these traces the first vertical graticule line at the left represents the horizontal zero reference; the amplifier gives zero output for negative values of the input signal. The following component values were used for the upper and lower traces respectively: R_{a1}, 150kΩ, 100kΩ; R_{b1}, 1.8MΩ, 1MΩ; R_{a2}, 100kΩ, 100kΩ; R_{b2}, 180kΩ, 180kΩ; R_{a3}, 100kΩ, 100kΩ; R_{b3}, 470kΩ, 470kΩ; R_{a4}, 120kΩ, 100kΩ; R_{b4}, 270kΩ, 270kΩ.

It is instructive to change component values and to note the effect of such changes on slopes and break points. Observed results should be compared with theoretically expected values. Discrepancies are to be expected because in the simple theoretical treatment of Fig. 6.2 diodes are assumed ideal and diode voltage drops are neglected.

Additional input networks may be added to the circuit in order to introduce additional straight line segments. Negative input signals may be made to produce an output signal by adding input networks with diode and reference voltage polarities reversed.

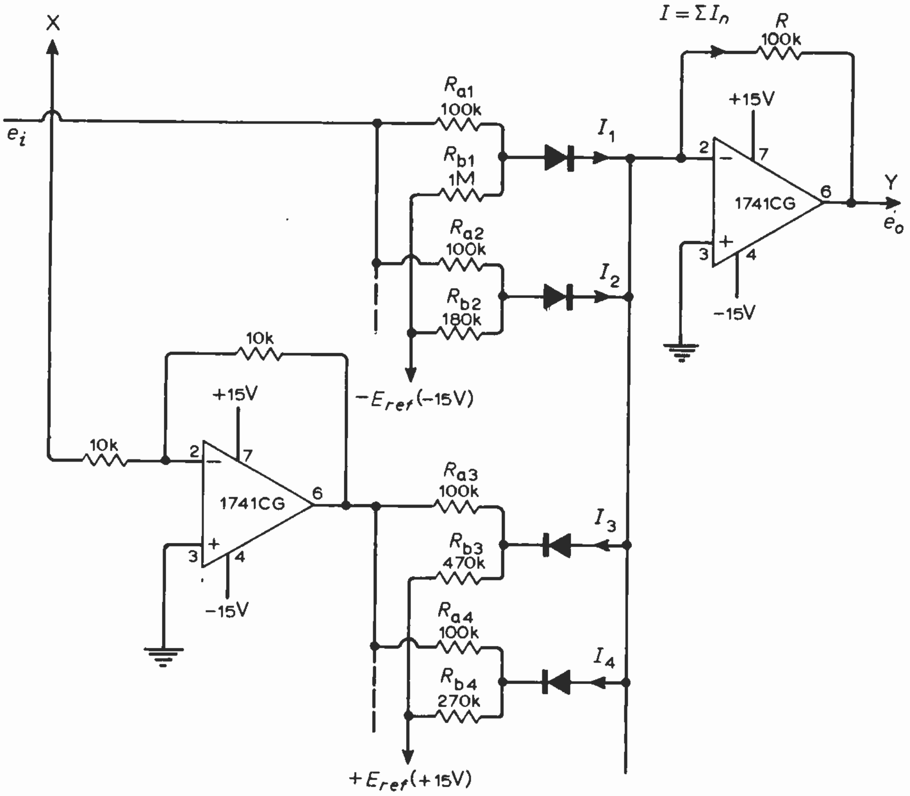

Fig. 6.1. Using an op-amp to sum a series of currents determined by resistors.

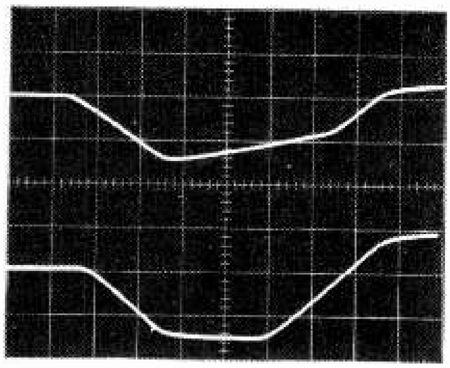

Fig. 6.3. Oscillograms of synthesized non-linear response. Horizontal and vertical scales, 1 V/div.

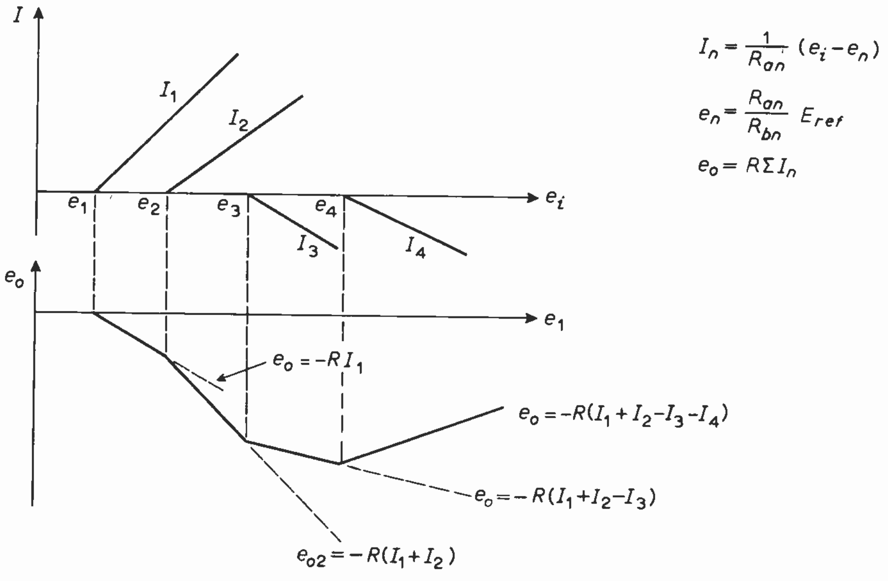

Fig. 6.2. Action of Fig. 6.1 circuit illustrated by graphs.

Sychronous Detection in Radio Reception — 2

Phase-locking and the "bi-aural" detector

by Pat Hawker, G3VA*

The main advantages of synchronous detection, as indicated in part 1 (September issue), are the modulation mode versatility it permits, its signal-to-noise ratio preserving qualities at low signal levels, and a good dynamic range when balanced forms are used. Further, the simplest applications of synchronous detection — product detectors for s.s.b. and direct-conversion receivers for s.s.b. and c.w. — do not require phase coherence. If full flexibility is to be achieved and synchronous detection used widely in receivers intended for the general public then something more is needed; some form of automatic control of the oscillator must be incorporated. History suggests that this needs to be done more elegantly than simply by triggering the local oscillator with a proportion of the incoming signal as proposed in the synchrodyne receivers. One must be able to lock the oscillator either directly to the incoming carrier or to control it from signals derived from the incoming sidebands.

First, it is worth having another look at direct conversion techniques. The very simple receivers outlined in part 1 can provide surprisingly good results with excellent selectivity, but they cannot achieve true "single-signal" reception as the audio image means that the receiver will respond to incoming signals on either side of the local oscillator frequency no matter how good the audio filter may be. Fortunately, this problem can be overcome, though at some cost in complexity, to the extent of some 30 to 45dB of rejection by the use of quadrature phasing techniques. A number of designs of what are termed two-phase direct conversion receivers have been published.

For example, Fig. 1 shows the block schematic of a 14-MHz receiver described by Taylor[1]; this provides true single-sideband reception by "phasing out" one set of sidebands in a manner akin to that used in phasing-type s.s.b. generators. In fact the designer used a standard Barker and Williamson phase-shift network in the audio combiner section. This technique is the same as that advocated for s.s.b. reception in such units as the Signal Slicer mentioned in part 1.

A basically similar approach was used by Spaargaren[2] in an experimental high-performance receiver for 3.5 MHz. In his receiver a cascode gain-controlled f.e.t. r.f. stage is followed by two balanced twin-diode detectors (Fig. 2) with the oscillator output phase shifted by 90° (Fig. 3) to provide phase quadrature injection. The a.f. outputs, after preliminary amplification, are similarly passed through active 90° phase difference networks (Fig. 4) and are then combined and passed through a five-section active low-pass filter to the main audio amplifier. He reported achieving 40dB of sideband suppression. Receivers of this type, while significantly more complex than the simplest direct-conversion receivers, are still basically simpler and cheaper to construct than a superhet receiver of comparable performance.

Further possibilities exist in this area. For example, the critical components in the phase shift networks could be eliminated by using digital i.c. techniques to provide the 90° phase shifts. A good deal of interest has been shown recently in digital phase shifting not only for possible simple s.s.b. demodulators for broadcasting[3] but also for s.s.b. generators, possibly based on the "third method" approach to s.s.b.

Phase-locked loop demodulators

The basic phase-locked loop synchronous demodulator, for example as used in the experimental receiver described by Costas in 1956 (Fig. 5), has been known for many years but until recently its use was confined to complex receivers such as those developed for space tracking. The incorporation of a phase-locked loop in a receiver means, among other advantages, that the receiver can utilize a noise bandwidth virtually equal to the intelligence bandwidth.

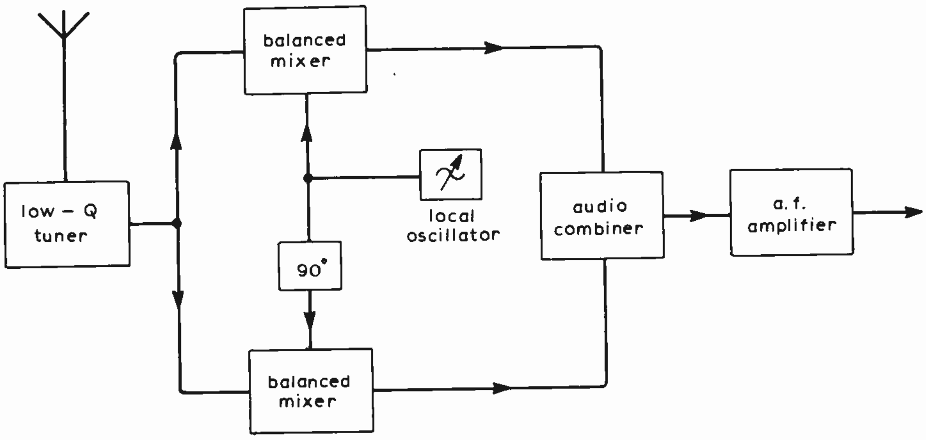

Fig. 1. Two-phase direct-conversion receiver providing "single-signal" reception for s.s.b. and c.w. signals.

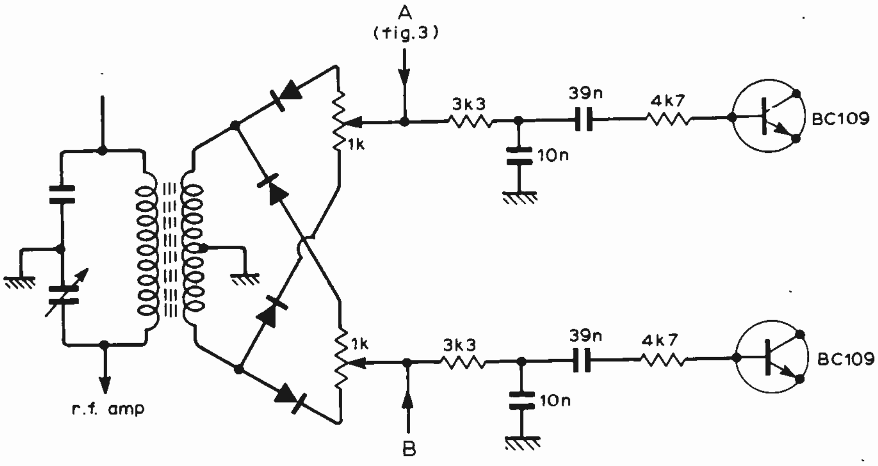

Fig. 2. Phasing-type balanced diode detectors for two-phase direct conversion receiver (Spaargaren).

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* Independent Broadcasting Authority

The position, however, has been dramatically changed by the present availability of integrated-circuit "signal conditioner and demodulator" devices[4] which provide a complete phase-locked loop demodulator in a single device — Fig. 6. Typically, such an i.c. contains a voltage-controlled oscillator, phase comparator, amplifier and low-pass filter. Some devices are intended only for f.m. demodulation, others include additional product detectors for other modes, including s.s.b. Such a device permits f.m. demodulation without any external tuned circuits — Fig. 8. The phase-locked loop can be externally tuned by a single adjustable element over a frequency range of 1Hz to more than 30 MHz. Within this range, a device such as the Signetics NE560B provides a tunable narrow-band filter with a selectivity comparable to that of three conventional tuned i.f. stages.

The phase-locked loop is an arrangement similar to that used in automatic frequency control circuits for many years but capable of maintaining the internal v.c.o. in phase coherence with the input signal. This means that the initial v.c.o. frequency need not be precisely tuned or unduly stable, as when within lock-in range it will automatically be drawn to the frequency of the input signal and held there.

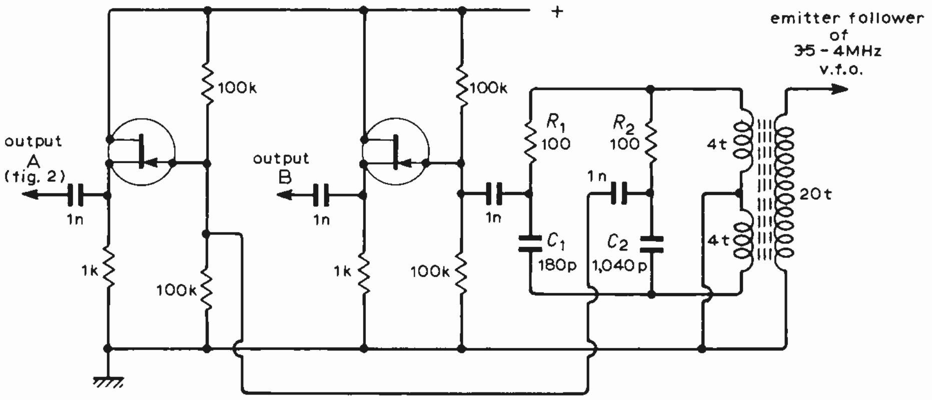


Fig. 3. Phase shifting networks used to obtain quadrature injection for the detectors of Fig. 2.

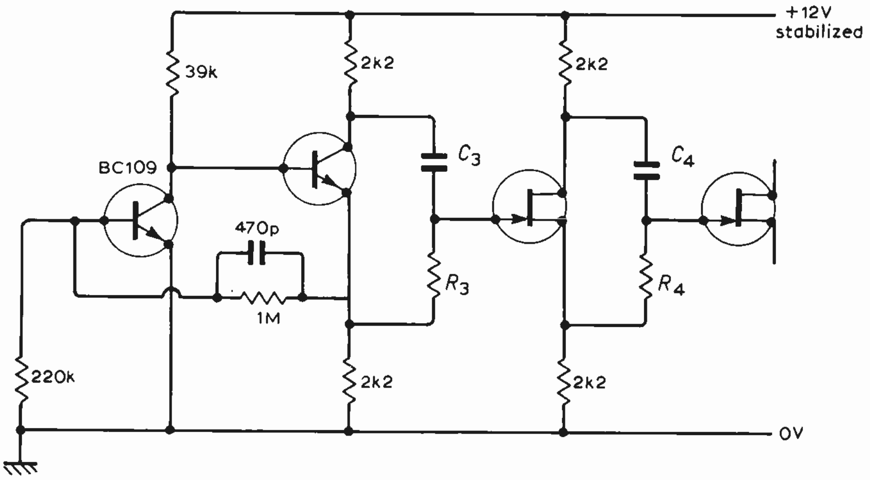


Fig 4. Principle of audio phase shifting networks. In one network C_3 is 4.7nF, R_3 220kΩ, C_4 4.7nF, R_4 18kΩ. In the other network C_3 is 1nF, R_3 800kΩ variable, C_4 1nF, R_4 20kΩ variable.

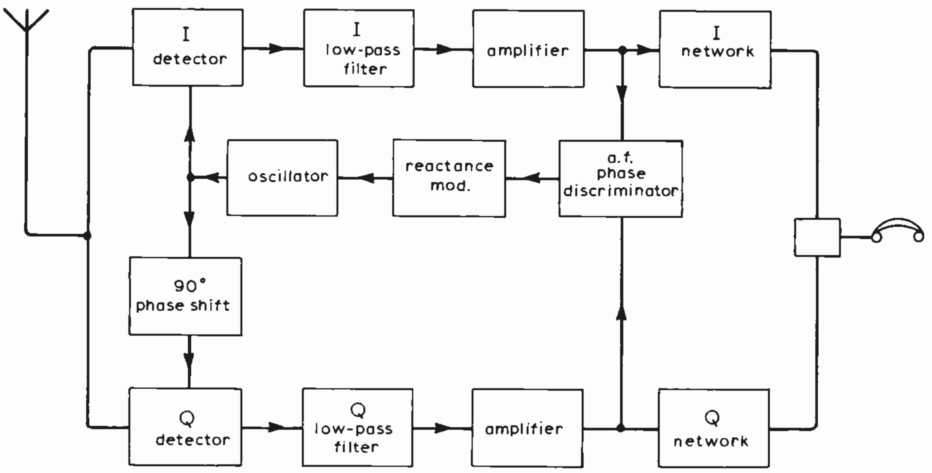


Fig. 5. Costas two-phase synchronous receiver for a.m., d.s.b.

For conventional f.m. or narrow-band f.m. the phase-locked loop provides a highly effective discriminator and eliminates the need for the usual ratio detector or quadrature f.m. detector on all signals above a low threshold value. W. N. Burridge has reported using an NE560B device as an f.m. detector for television sound and found it functioned extremely well on long-distance signals, receiving Crystal Palace in south Devon — see ref. 5. He has also used the NE561B as an a.m./f.m. demodulator on amateur 144MHz and 432MHz signals, using an i.f. of 1.6MHz.

Among the applications suggested[6] by Signetics for their NE560/NE561 devices are: i.f. strip and demodulator for f.m. receivers; television sound i.f. amplifier and demodulator; tuned a.m./m.w. receiver of the direct-conversion type (Fig. 9); "storecast" (s.c.a.) receivers and the like.

It must be admitted that the cost of these purpose-designed demodulators has so far remained high for amateur experimenters, but some lower-cost units are available for use as narrow-band f.m. demodulators at intermediate frequencies up to 500kHz.

Recently, K. Spaargaren has shown that it is possible to achieve comparable results using three of the relatively low-cost t.t.l. integrated circuits plus a few external components — Fig. 10 and ref. 7. By adjustment of *C* this system can be used at virtually any frequency up to about 30MHz. One section of an SN7400 is used as a voltage-controlled oscillator with the frequency determined roughly by *C*, and brought into accurate lock by the output of the phase detector connected via a BC109 transistor.

Bi-aural demodulator

The basic phase-locked loop detector can be extended still further by its use in conjunction with quadrature phasing techniques and dual audio channels to provide high performance on almost all possible broadcast modes. This system is generally termed a bi-aural synchronous exalted-carrier detector — Fig. 11.

In this detector two balanced mixer-modulators (usually at i.f. but again the system could be adapted for direct conversion) are driven in phase quadrature from the controlled local oscillator to provide in-phase (*I*) and quadrature (*Q*) product detectors. The d.c. and a.f. output from the *Q* detector is used to lock the local oscillator to the incoming signal. The d.c. output from *Q* can be used to operate a tuning meter, and when in lock the d.c. output of the *I* detector provides an indication of the incoming signal strength and so can be used to operate an S-meter

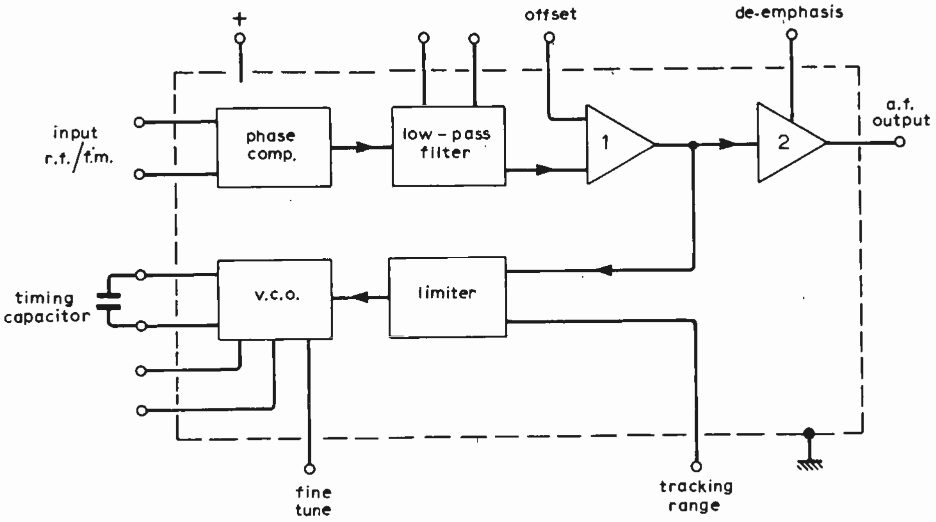


Fig. 6. Block outline of NE560B phase-locked loop demodulator integrated circuit.

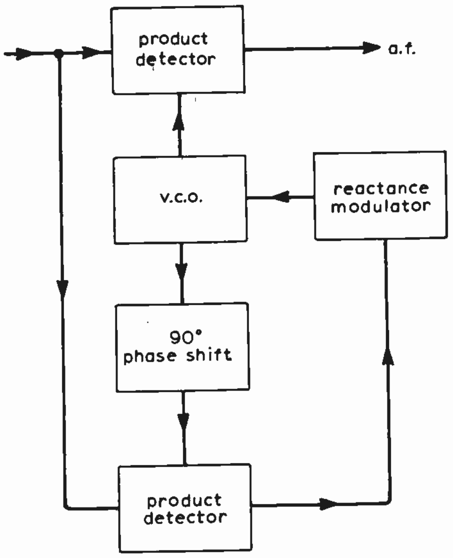


Fig. 7. Synchronous lock-loop demodulator.

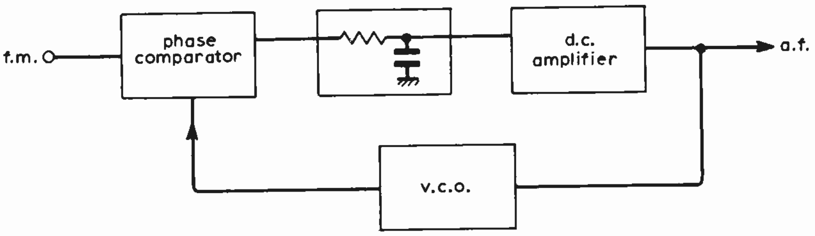


Fig. 8. Basic phase-locked loop f.m. demodulator.

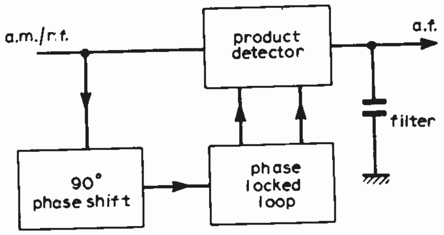


Fig. 9. Use of an NE561 i.c. as a simple direct-conversion receiver for medium-wave a.m. reception.

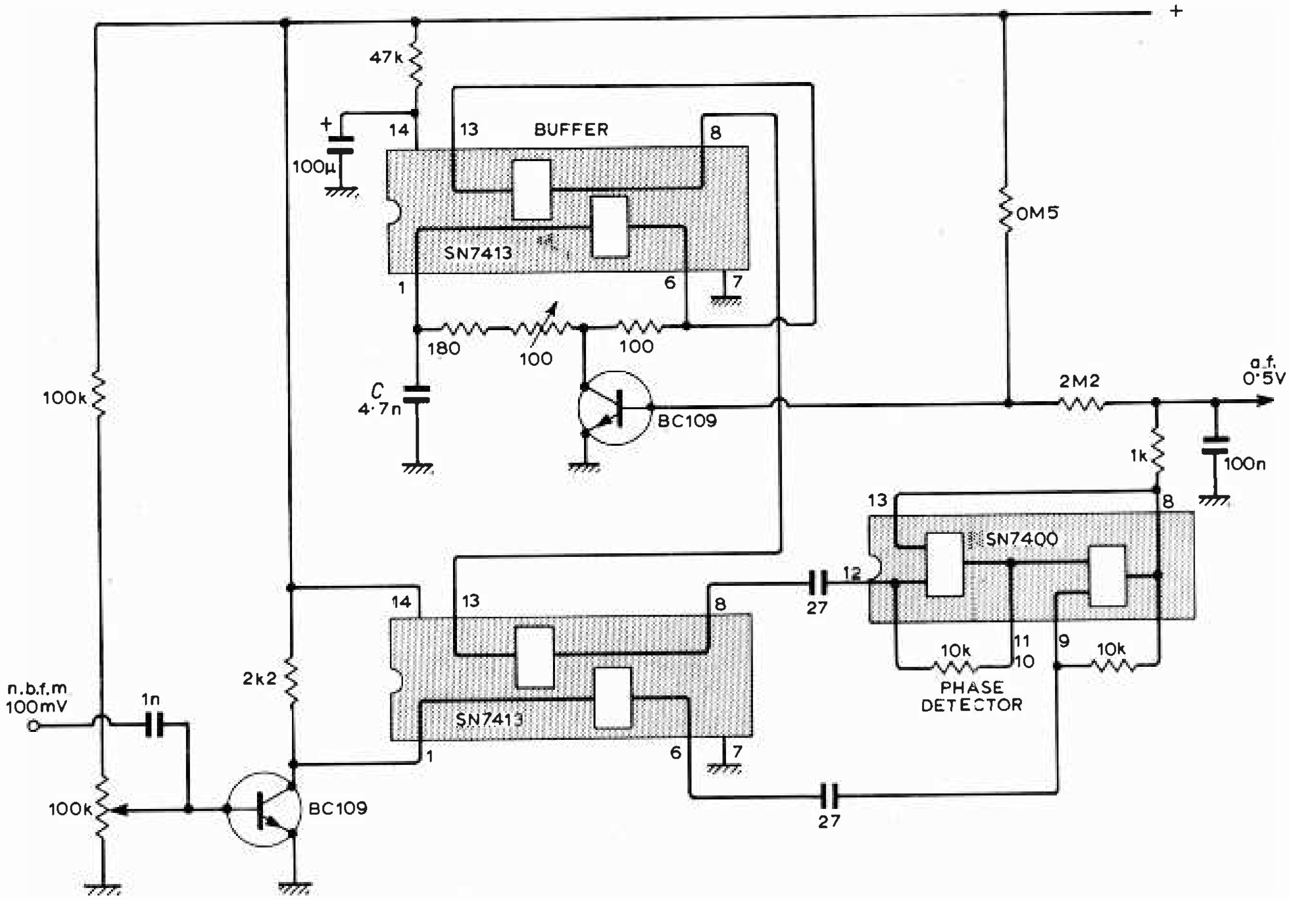
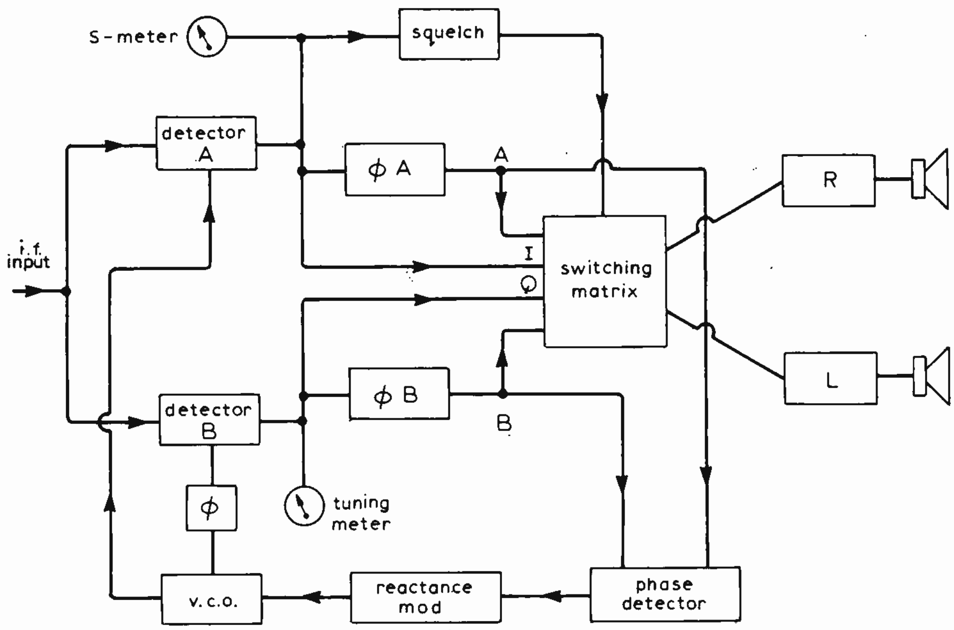


Fig. 10. Use of low-cost t.t.l. digital integrated circuits to form phase-locked loop n.b.f.m. demodulator. With value of C indicated, this is suitable for intermediate frequencies of around 470kHz (Spaargaren).



SWITCH MATRIX	AUDIO R	AUDIO L
1 a.m./d.s.b.	I	I
2 f.m.	Q	Q
3 reject u.s.b.	A+B	A+B
4 biaural	A+B	A−B
5 reject l.s.b.	A−B	A−B

Fig. 11. Flexible bi-aural synchronous exalted-carrier detector.

Relative effectiveness (in dB) for speech in the presence of random interference showing influence of the demodulator (after Haviland).

Mode	Envelope detector	Slope detector	Product detector	'Select' product	Locked loop	Bi-aural
d.s.b. (10kHz)	−3.2	—	−6.2	−3.2	−3.2	+2.8
n.b.f.m. (10kHz)	−20.4	−7.4	−10.4	−7.4	−7.4	−1.4
s.s.b. + C (5kHz)	−3.4	—	−0.4	−0.4	−3.4	−0.4
s.s.b. (5kHz)	—	—	+10	+10	+7	+10
d.s.b.s.c. (10kHz)	—	—	+7	+10	+10	+16

or a squelch arrangement to mute the receiver between stations to eliminate tuning heterodynes.

The *I* and *Q* outputs are passed through two phase shift networks (A and B) and then go to a switching matrix, arranged to give sum and difference components or direct outputs from the detectors. From this matrix, outputs are taken to two separate audio amplifiers and loudspeakers, as in stereo practice, although this is not a stereo system.

The detection system, as reported by C.C.I.R. Study Group 10, operates as follows. When receiving normal a.m., its a.f. component appears in the output of the *I* product detector, but no output appears at *Q*. In these circumstances, a.f. is fed to both *L* and *R* channels except with the matrix switched to position 2. The listener "hears" the source midway between the loudspeakers.

Should non-synchronized interference be present, it will appear in the outputs of both *I* and *Q* detectors and at the outputs of the A and B networks. With the switching matrix in position 1, the interference appears in both loudspeakers. But, depending on which sideband the interference is affecting, it will be rejected in either position 3 or 5 of the matrix.

In position 4, the wanted audio appears on both loudspeakers but the unwanted signals, provided they affect only one sideband, appear on only one loudspeaker. It appears to the listener displaced in position and he is able to ignore it. In this position, in practice, there may be interference on both sidebands, but the listener is still able to reject it as only the wanted audio will appear to be coming from the central area.

If the signals are fading, the relative strength of the wanted and unwanted signals changes. But in the case of selective fading of the wanted signal, this will result in an apparent moving of the source from the mid-point between the loudspeakers resulting from the simultaneous amplitude and phase changes; but it is claimed that the usual "garbling" produced by selective fading normally does not occur.

For reception of phase-modulated or narrow-band f.m. signals, performance will be similar apart from the fact that the a.f. output of the *I* detector is zero, with the output of the *Q* detector containing the wanted signal.

For the reception of s.s.b., an output will appear at both *I* and *Q* mixers with the unwanted sideband providing a null signal which can be rejected by switching either to position 3 or 5. It has been stated that with careful design of the phase-locked loop it is possible for the local oscillator to be locked by the incoming carrier even when this has been suppressed to the extent of 40dB. The system can still be used for greater degrees of carrier suppression as it then functions as an un-locked product detector, but becomes subject to tuning errors.

Study Group 10 has suggested that it is difficult to assess the improvement over a conventional detector of this system, at least on a theoretical basis, but tests have suggested that average improvement in reception is around 10 to 20 dB and interference rejection may in some circumstances reach 30 to 40dB, the value depending on the accuracy of the phase shift networks. It is also believed that the "presence" of programme material is enhanced by the geometric effects arising from the two audio channels.

The value of this form of bi-aural demodulator is also indicated in the Table, drawn from reference 9. It should be stressed, however, that this form of improved synchronous detector is only one of a number of improved forms of detectors which are under investigation in the feasibility studies for s.s.b. broadcasting.

All the ideas discussed in these two articles utilize the various properties of synchronous detection, from relatively simple product detectors already widely used to the quite complex bi-aural system outlined above. In addition there are many other, often even more exotic, applications in communications and instrumentation which already use — or are likely in future to use—synchronous techniques.

Concluded. (Readers may have noticed that captions to Figs 6 and 7 in part 1 were transposed in error.)

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Pat Hawker, "Technical Topics", *Radio Communication*, February, June, July, September, December 1971.
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Digital and Analogue Dividers

The digital display of a quotient from analogue or digital information

by P. R. Darrington

Several times in the last few years the author has been presented with the problem of providing a display of a quotient from analogue or digital dividend and divisor. The original impetus for the development of a series of circuits to perform the dividing function was a requirement by a weighing-machine manufacturer for a machine to determine the number of small objects in a batch of similar objects.

The method adopted was to weigh, by means of small and large machines, one object and the complete batch, dividing the latter by the former to obtain the number. Tare weights of containers were accommodated mechanically on the large machine. The weights indicated by the weighing machines were translated into electrical signals by means of diffraction gratings mounted on the machine spindles, the interference fringes produced by the rotation of the spindles providing both a train of pulses and, after logic operation, information as to the direction of rotation.

At a later stage, the requirement arose for the weighing to be carried out by load cells and other devices, such as linear variable differential transformers, the analogue information thereby derived dictating a different approach to the division function.

Both the earlier digital method and the analogue system have been used in operational equipment, to accuracies consistent with the industrial environment, the actual accuracies of the machines being limited to some extent by the input transducers available. The digital system has since found application in another area, namely that of direct-reading, very low-frequency indication, an example of which is described.

Digital divider

A basic block diagram is shown in Fig. 1, in which it is convenient to ignore the input circuitry and to assume that counters A and C are in the states corresponding to the weights of sample batch, the input circuitry being devoted to the generation of signals for the counters.

Counters A and C are continuously compared with counters B and D in digital comparators E and F. Fig. 2 shows a one-bit comparator which gives an output only when the inputs from circuits A and B are in the same state; a full comparator uses two such gates for each bit, i.e., eight gates for a decade counter, "wire-ORed" together.

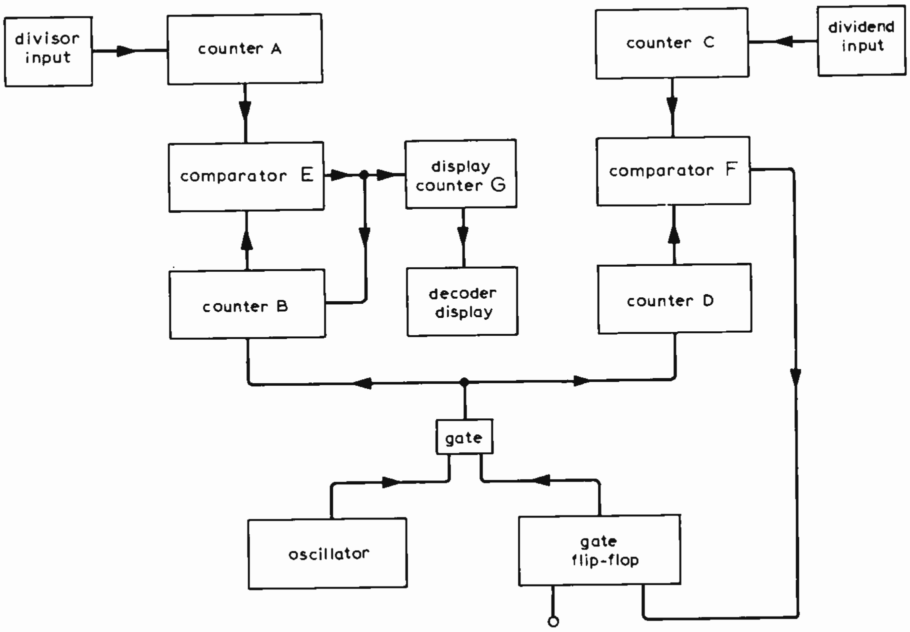


Fig. 1. Skeleton block diagram of the sequential digital divider.

Operation proceeds as follows. The gate flip-flop (Fig. 1) is actuated by a push-button, its output being arranged to open the gate, allowing pulses from the clock oscillator to pass to counters B and D. When counter B has accumulated sufficient pulses to bring it into coincidence with counter A, the digital comparator E produces an output which is taken to the reset input of counter B, resetting it to zero. The output of the comparator also goes to the display counter G, which thereupon counts one pulse.

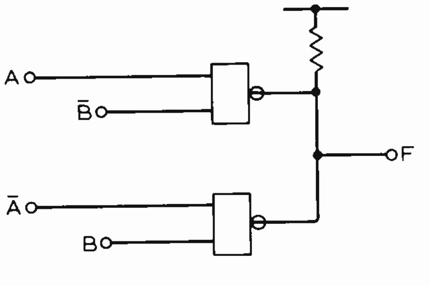


Fig. 2. One-bit element of a digital comparator. F is up when inputs from flip-flop A and B are in the same state.
$F = A\bar{B}+\bar{A}B = (\bar{A}+B)(A+\bar{B}) = AB+\bar{A}\bar{B}$

This sequence of events continues, one pulse being fed to the display counter G every time the oscillator emits the same number of cycles as are held in the sample input counter A. During this time, counter D is counting up towards coincidence with batch input counter C, and when this is achieved, comparator F switches, resetting the gate flip-flop and closing the gate. Display counter G is now in the state corresponding to the number of times that the contents of sample counter A is contained in batch counter C; in other words, the number of objects in the batch.

The contents of the display counter can be used to display the number, to provide a print-out or other data-processing outputs or, in conjunction with a further digital comparator and input switches, to control activities of a feed hopper.

Accuracy

The error of the system is one count in display counter G, neglecting the error introduced by the weighing equipment or whatever type of input transducer is used. When used in the object-counting application, there are obviously no fractional results; however, used in other systems,

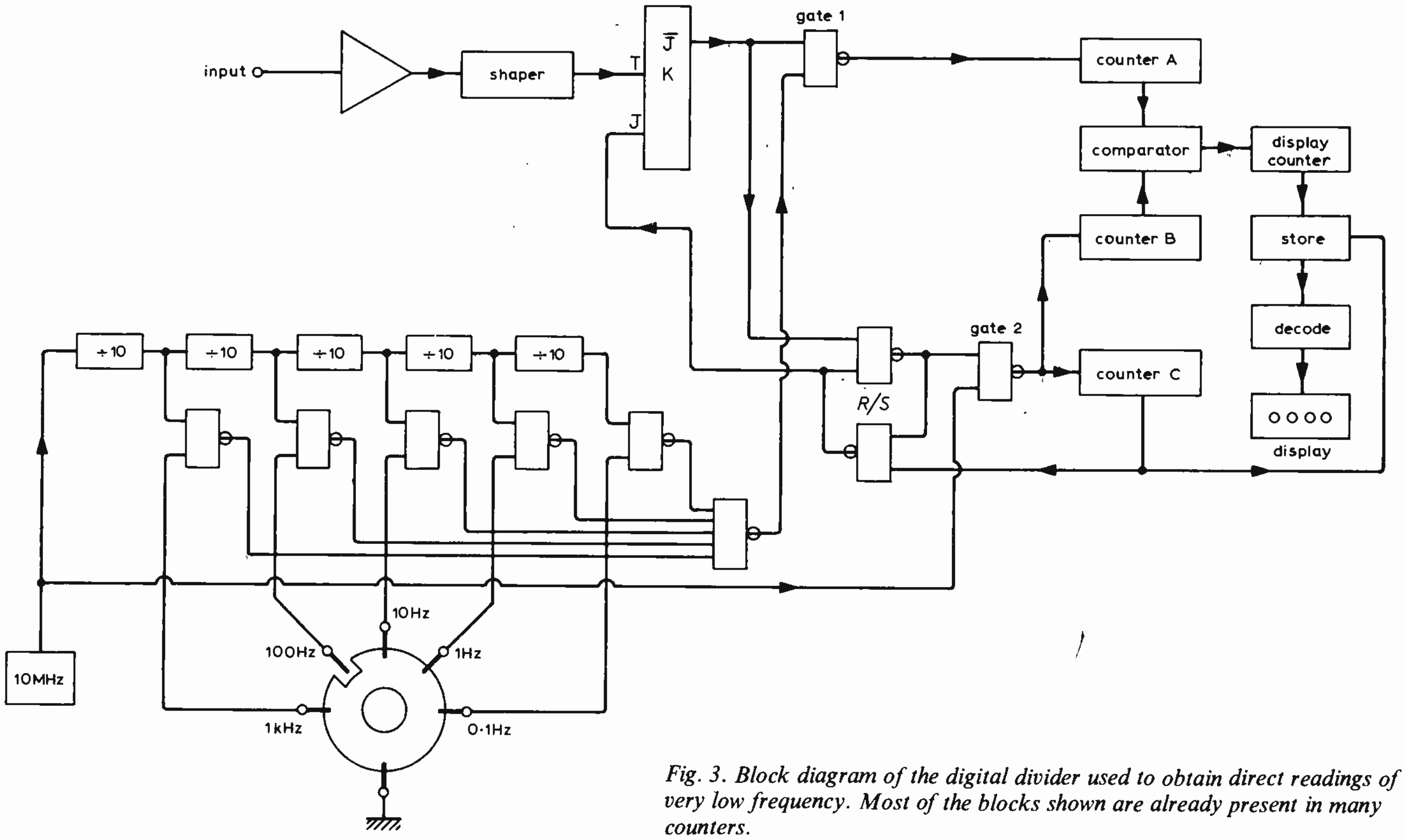


Fig. 3. Block diagram of the digital divider used to obtain direct readings of very low frequency. Most of the blocks shown are already present in many counters.

results accurate to as many decimal places as required may be obtained by the addition of a number of artificial, permanent zeros in counter C.

Frequency meter

The digital measurement of frequency by the conventional method of counting the number of cycles of the input that occurs during a known time interval is well-established, accurate and in most cases extremely convenient. Accuracy of measurement, in terms of resolution is in direct proportion to frequency however, and in the limit approaching 1Hz there is only one cycle during a one-second gate time. The possible error, bearing in mind the inherent ±1 error in any counter where the clock is not phase-related to the input signal, is 100% of reading.

The usual way of overcoming the increased error, apart from lengthening the gate time, a process to which there is a limit set by the operator's store of patience, is to reverse the procedure, measuring the number of cycles of a known, high frequency that occur during one period of the input. The displayed result now gives the reciprocal of frequency, to a much greater resolution than that given by the reverse procedure simply because there are more significant figures displayed, and the inherent one-count error is not so important.

This display of periodic time is perfectly adequate for laboratory work, where time and inclination are both in fairly good supply, but when a direct reading of frequency is required, slide rules and reciprocal tables are poor substitutes. The measurement of, for instance, pulse or respiration rate in an operating theatre is required to be both rapid and trouble-free and mental arithmetic is to be avoided.

The system to be described surmounts the problem by the use of sequential dividing logic to perform the calculation $f = 1/t$. A block diagram is shown in Fig. 3, and it will be seen that most of the blocks are already used in any counter which is capable of periodic time measurement.

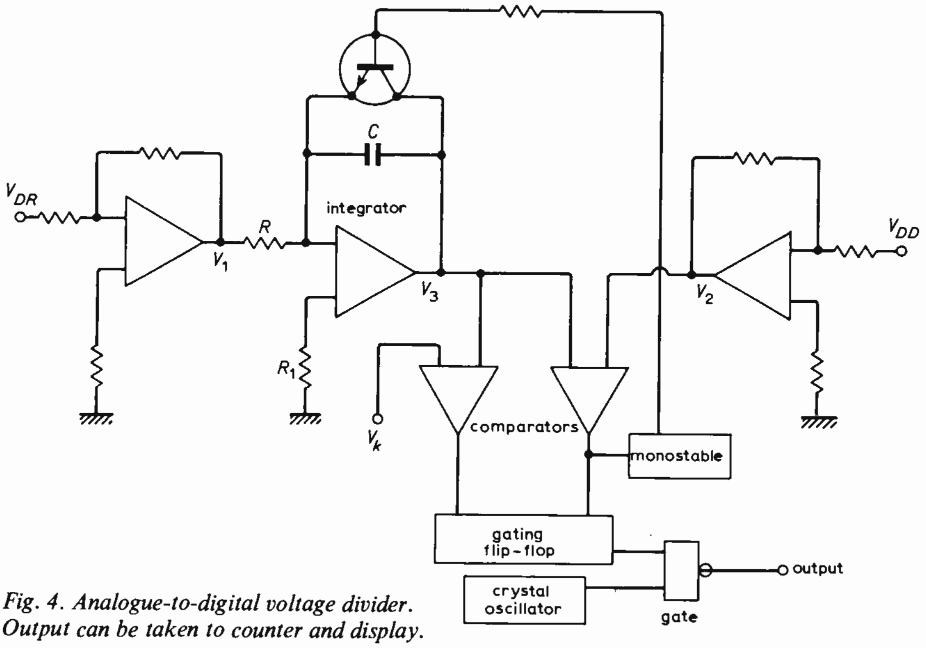


Fig. 4. Analogue-to-digital voltage divider. Output can be taken to counter and display.

Principle of operation

The circuit consists almost entirely of decade counters and digital comparators, as in the case of the counting system already described. The input signal, after shaping, triggers a J-K flip-flop which opens gate 1. Constant-frequency pulses, which are a selected sub-multiple of 10MHz, pass to counter A. One period of the input later, the gate closes, the counter now having adopted the state equivalent to the periodic time of one cycle of the input. So far, the operation is exactly that of a periodic time counter.

However, when the J-K flipped in such a direction as to close the gate, the output also triggered the R-S flip-flop, inhibited the J-K and opened gate 2 to counter B, which is thereupon fed with 10MHz signals.

Counter B is connected to a comparator in opposition to counter A and when the two are in coincidence, the comparator detects the fact and produces a pulse. The function of the pulse is two-fold; firstly, it resets counter B to zero and secondly, it steps the display counter to one count. The cycle then repeats, counter B continually counting forwards to coincidence and being reset to zero, and the display counter recording the number of complete cycles.

The output of gate 2 is also taken to counter C, which in one second produces a "spill-over" pulse at 10^7 cycles, which is used both to flip the R-S flip-flop, so closing gate 2, and to transfer the contents of the display counter to store, decoder and display. The J-K is switched to open gate 1 and the whole operation begins again.

The display now indicates the number of times that the contents of counter B are contained in (divided into) 10^7, which is the capacity of counter C. The initial measurement was $t = 1/f$, which has now been converted into $f = 1/t$.

An example will demonstrate the benefits of the system. If the input were 1Hz, a direct measurement of frequency to a resolution of 0.1% would take just under 17 minutes. Using the method described, the time taken consists of one cycle of the input (one second) plus the time for a 10MHz oscillator to emit 10^7 cycles (one second), giving a total time of two seconds. The units of periodic time registered by counter A are switched so that between 10^3 and 10^4 pulses are recorded, giving a displayed result to a resolution of $10^7/10^3$ or $10^7/10^4$ (10^4 or 10^3) units, depending on which end of a range is in use.

All the logic can be realized with small or medium-scale integrated circuit modules, and so far as the calculation of the reciprocal is concerned, the oscillator can be of any frequency and not particularly stable. It is simply convenient to keep the frequency as high as possible to shorten the calculating time, and to use the existing crystal oscillator possessed by most counters.

Analogue dividers

The circuit to be described possesses the merits of speed and simultaneous conversion of input voltage analogue to output digital presentation. It requires no exotic devices, is extremely simple in concept and depends for its accuracy chiefly on the gain and stability of an operational amplifier used in the integrating mode. As the circuit was originally intended for use with the weighing machine described earlier a facility is included to enable a constant to be extracted. This was necessary to take account of the weight of the container.

Principle of operation

A general functional diagram is shown in Fig. 4. Voltages V_{DR} and V_{DD} represent the divisor and dividend respectively, V_K being adjustable or fixed permanently a little positive of zero. The input amplifiers are ordinary operational types of sufficient gain and stability to allow the feedback and drift performance consistent with the application.

The negative-going output V_1 of the V_{DR} amplifier, becomes the input to the integrator, whose time-constant is CR. The current through R and therefore C causes the integrator output voltage to perform a linear, positive-going ramp which, when applied to the two comparators is in coincidence with V_K and V_2 in succession, V_2 being the output of the V_{DD} amplifier. At each coincidence, a pulse from the comparator output circuit is applied to the flip-flop and gating circuit to control the output, a train of pulses which can be counted and displayed.

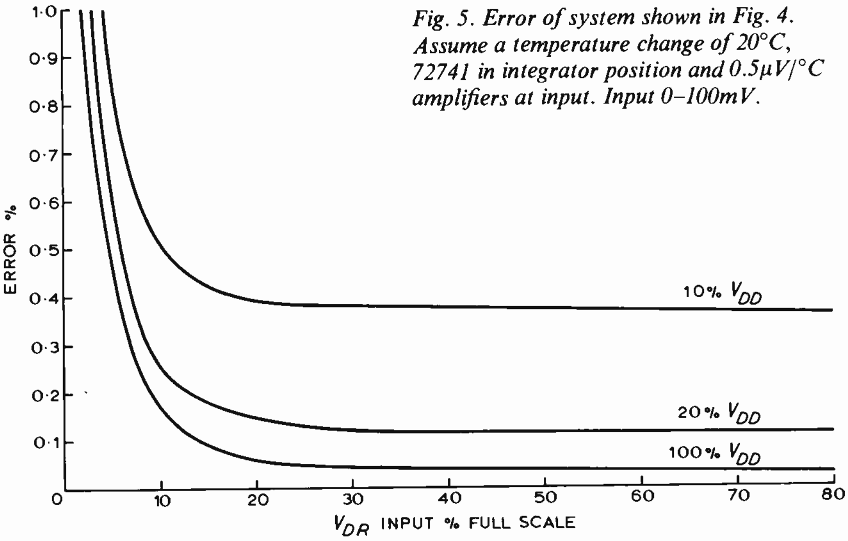


Fig. 5. Error of system shown in Fig. 4. Assume a temperature change of 20°C, 72741 in integrator position and 0.5μV/°C amplifiers at input. Input 0–100mV.

The cycle repeats after the second coincidence, a pulse from the monostable being applied to the transistor across the integrating capacitor, causing it to be discharged.

The time between coincidences, and therefore the gating time, is given by:

$$t = \frac{CR(V_2 - V_K)}{V_1}$$

The value of CR is a constant, so that t represents the quotient, V_K also being a constant and returned to a fixed voltage if desired. Scaling of t is determined by the value of CR and the gains of the two amplifiers, and by the frequency of the oscillator.

Accuracy

Accuracy of the transfer characteristic is dependent on the stability of the two input amplifiers and the integrating amplifier. Errors inherent in the divider circuit, as opposed to those concerned with the input amplifiers are attributable to the finite voltage gain and input voltage and current offset drifts of the integrator. The output excursion of the integrator is V_3. Of this, $-V_3/A_{Vol}$ appears at the amplifier input, where $-1/A_{Vol}$ is the fraction of the output appearing at the integrator input. This voltage is effectively in series with the input voltage V_1 and causes the "constant" current through R, which should be V_1/R, to become $[V_1 - (V_3/A_{Vol})]/R$ resulting in a non-linear ramp. Input voltage offset drift modifiers V_1/R to $(V_1 \pm \delta e_{os}T)/R$, where δe_{os} is a small increment of input voltage dependent on the temperature, T. Input current offset drift can be almost entirely nullified by the correct balancing of R and R_1. Assuming worst-case conditions of minimum V_1 and maximum V_2, and using a 72741 as integrator, a temperature change of 20°C will cause an error of about 0.04%, which, of course, is modified by the drifts of the input amplifiers. The somewhat sluggish comparator switching using open-loop 72741s is unimportant, as both comparators impose identical delays, the overall effect being to delay the whole output.

Fig. 5 is a graph of the output time error for a range of input voltages, errors being additive for the worst-case condition. It can be seen that the error *expressed as a percentage of reading* increases sharply at low inputs, as is to be expected with any system. However, it was felt that as the final result bears no obvious relationship to either input, taken separately, it would be meaningless to express the error as a percentage of the maximum quotient. Input amplifiers are assumed to have input voltage offset drift of less than 0.5μV/deg. C.

The output can be displayed in the same way as described for the digital divider and can be used for data-processing purposes or used to give a signal when a preset quotient is achieved.

The circuits described are only two of the many possible ways of performing the division function. Logarithmic amplifiers, voltage-controlled oscillators used with a frequency ratio counter and analogue-to-digital converters with l.s.i. calculator chips are all feasible, but suffer from inaccuracy or relatively high cost. The two described work well and can be built cheaply enough for industrial use.

Wireless World Diary

This annual *vade-mecum* is now available. It contains, in addition to the week-at-an-opening diary, a 64-page section giving both technical and general information. This section includes addresses of radio and electronics organizations in the U.K. and overseas, design formulae, television standards, circuit building bricks, logic functions and frequency allocations to the various services, to mention but a few headings.

The Diary, which is published in conjunction with T. J. and J. Smith Ltd, is obtainable from booksellers and stationers or direct from T. J. and J. Smith Ltd, Deer Park Road, London SW19 3UT. It costs 54p, plus 8p postage.

News of the Month

Man-made communications crystal

A clear, man-made crystal has become the first synthetic alternative to quartz for communications equipment. The crystal, called lithium tantalate, was designed by Bell Laboratories to improve telephone transmission equipment and is now being produced in North Andover, Mass., at the Merrimach Valley Works of the Western Electric Company.

Lithium tantalate, like quartz, can be used to produce or absorb precise vibrations or frequencies, and thereby serve in a frequency filtering device. In the last 30 years, quartz has been the only piezoelectric material to be used extensively in the communications industry and although about a hundred piezoelectric materials have been investigated, until now none has exhibited the necessary combination of characteristics to complement quartz for filtering functions. Many special properties are required, including relative stability and insensitivity to temperature changes. Unlike quartz, lithium tantalate does not occur in nature and must be grown at high temperature from a melt of lithium oxide and tantalum pentoxide. The crystal boule, about three inches by three-quarters of an inch in size, is cut into small rod-shaped crystals, a few millimetres thick and a few centimetres in length. The bandwidth limitation of quartz led to the search for a material which has all the desirable features of quartz, but which also has a stronger electro-mechanical coupling constant to provide the wider bandwidth. Lithium tantalate has electro-mechanical coupling "five or six times better than quartz"

Hong Kong's exports of electronic equipment

Hong Kong's exports of transistor radios increased to £26.8M during the first six months of this year, a 27% rise when compared with the same period last year, reports the Hong Kong Trade Development Council. Major markets were the U.S. which took 58% of the total, followed by Britain which accounted for a 12% share and West Germany with 7%.

Hong Kong's £25.9M worth of exports of electronic parts and components during the first six months of this year also were an increase of 24% over January/June 1971. Major markets were the U.S. which took 78% of exports followed by Taiwan, Singapore and West Germany.

The colony's exports of computer parts, by comparison, showed an 8% drop during the first six months of this year with shipments — mainly to the U.S., West Germany, Britain and France — totalling £8.6M.

Exports of electronic calculating machines have shown tremendous growth, with shipments during the first seven months of this year totalling £344,000 as compared with only £2,400 for the same period last year.

Stereophonic broadcasting

The B.B.C. has completed the first stage of the work necessary for the introduction of stereo broadcasts on Radio 2, in addition to those on Radio 3. The new service on Radio 2 started on November 4th. A large proportion of the music programmes on Radio 2 will be in stereo. The transmissions will initially cover those areas served by the transmitter at Wrotham, Dover, Rowridge and Brighton.

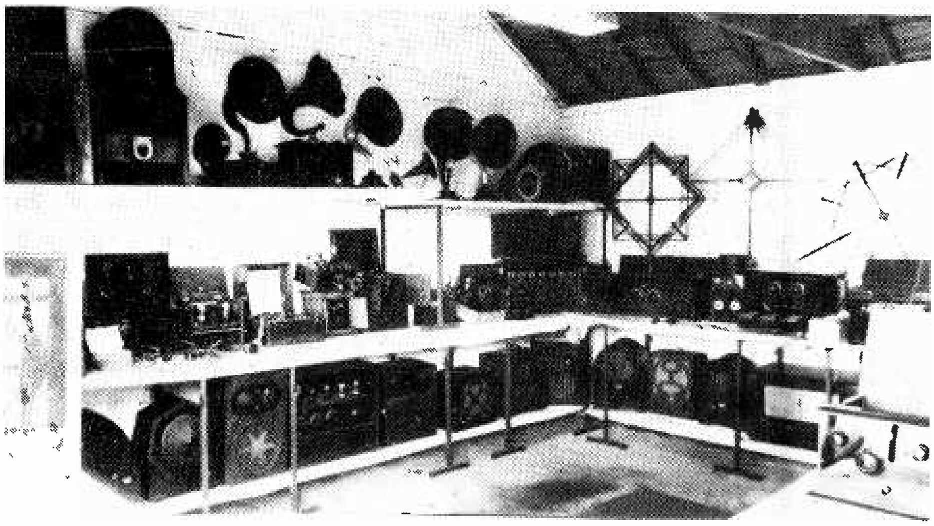
During October, a number of programmes are being broadcast in stereo from these transmitters, as part of a test period which is intended to help listeners, the radio trade, and the B.B.C. to deal with any problems which may arise. For operational and technical reasons, it is intended initially to transmit the pilot tone continuously during programme hours. This means that on receivers equipped with a stereo indicator this will light up, whether the programme is in stereo or not.

The Radio 2 stereo service will be extended to the Midlands in November and to the North of England early in 1973. Subsequently it is planned to extend the full stereo service to Central Scotland, the Bristol Channel area, and to other parts of the country. These extensions have been made possible by the development by the B.B.C. of a new system of network distribution based on the use of pulse code modulation, which is already in use on a test basis between London and the Wrotham transmitter. This system will not only make it possible to extend the stereo service but also offers the prospect of a higher and more consistent standard of sound quality from transmitters in every part of the country for mono as well as for stereo.

Pacific ship-shore radio

In co-operation with shipping companies, the Post Office has begun an experiment to improve communications with ships crossing the North Pacific ocean. It is particularly difficult for ships in this area to contact Britain by short-wave radio. Focal point of the experiment is the Post Office's long-range radio station centred on Burnham-on-Sea, Somerset.

Under normal procedure, the Post Office operators at Burnham continuously listen for calls from ships by "searching" the scores of different maritime radio frequencies. To establish contact, the radio operator's receiver at Burnham must be tuned to the ship's transmission frequency at the instant her radio officer sends his call — largely a matter of chance. On most occasions the radio officer does not have to call more than a few times before



As a follow up to our news item "Vintage wireless society" which appeared last issue, this photograph shows some of the equipment which has been collected for viewing at the society's museum in Lincolnshire for wireless and electronic apparatus. Anyone wishing to pay a visit should ring the Hon. Curator at 077-584 485.

being heard, except from the North Pacific. Between this area and Britain there is frequently radio black-out for most of the twenty-four hours. As ships can only call Britain in the few short periods when communication is possible, severe congestion results, and the chances of each call being heard are even further reduced.

A new procedure has been set up to make it more likely that every call to Britain from the North Pacific will be picked up in this country. The region has been divided into five sectors and different times have been fixed for communication with each sector: this, the Post Office hopes, will increase the possibility of the weaker signals from these areas being heard. In addition, special frequencies have been selected — one from each of six maritime bands — for use only by ships in the North Pacific. The radio operator at Burnham, listening at the pre-arranged call times, need no longer "search the bands", he tunes his receiver to one frequency only and Portishead Radio sends out a special signal to tell ships' radio officers which frequency it is. In addition, the receiver at Burnham is connected to a directional aerial pointed towards the area from which the signals will come to create an even better chance of hearing the call.

QSL cards from the B.B.C.

In November, when the B.B.C. celebrates its 50th anniversary, there will be a chance for listeners to the B.B.C. World Service programme, World Radio Club, to possess a rare B.B.C. QSL card, verifying reception of the club's 50th anniversary edition.

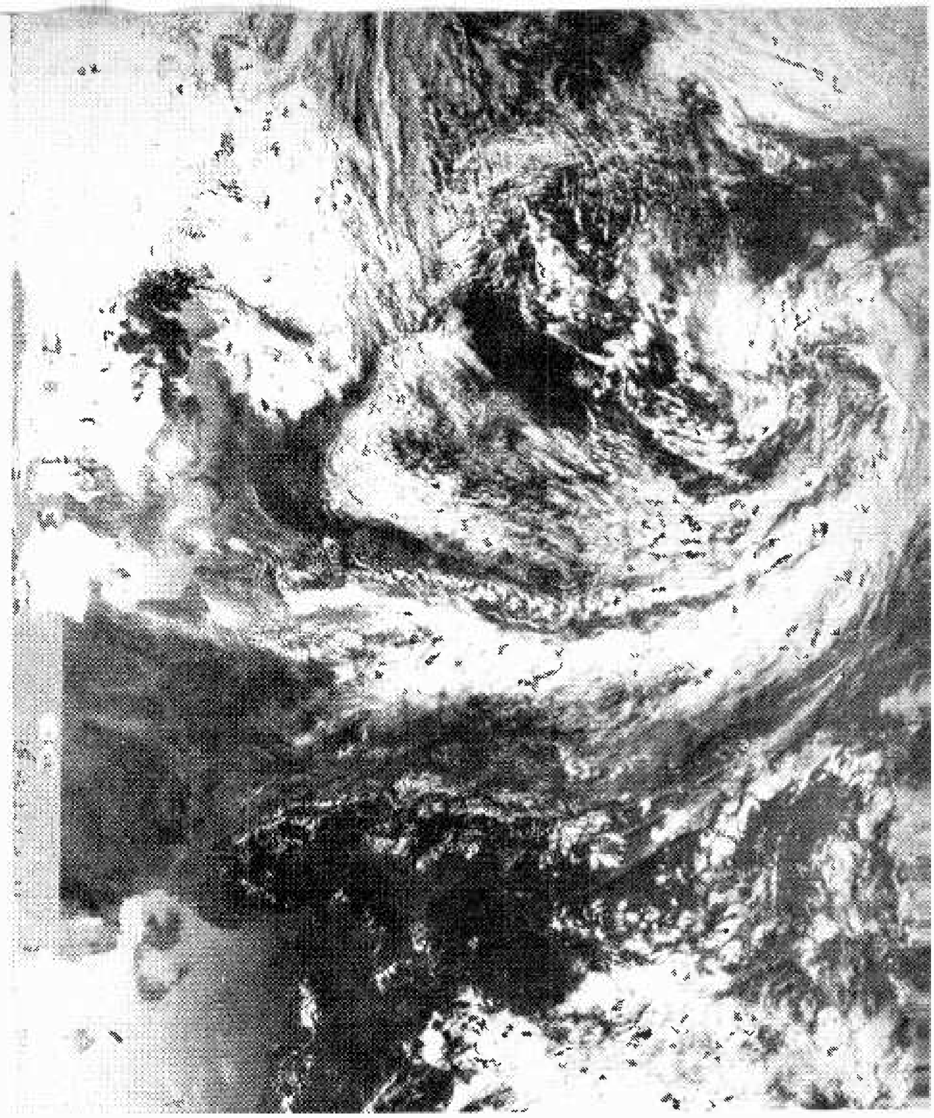
World Radio Club is broadcast on Thursdays at 13.30, Fridays at 23.45 and Sundays at 08.15 G.M.T. in the World Service, and any member who reports accurately on reception of the anniversary edition on November 9th, 10th or 12th will receive this special QSL card. The address is: World Radio Club, B.B.C., Bush House, Strand, London WC2B 4PH.

End of the Shipress era

September 30th marked the end of an era in shore-to-ship news transmissions, with the close down of Shipress (GTZZ) by Wireless Press Ltd, London. Reductions in many passenger fleets led to the decision to sign off an automatic, twice-nightly morse service to ships at sea.

First experiments in regular transmission of news telegrams to ships involved Browhead, Ireland, wireless station and the Cunarder *Etruria* on February 7th, 1903. Later that year the Cunarder *Lucania*, ex-Liverpool, assisted with the inauguration of a daily news service via Poldhu, Cornwall and Glace Bay, Newfoundland.

The Wireless Press Ltd, which originally published *Wireless World*, was owned by the Marconi Company until its acquisition by Associated Iliffe Press Ltd, in 1924. Post Office stations involved from 1926 were Leafield, Oxfordshire, Rugby and latterly, Portishead. Principal news agencies contracted over the years were Reuter and Press Association and since 1967 the London bureau of United Press International prepared editorial copy for the service which was received by radio officers aboard troopships, ocean-going yachts and cargo ships in addition to British, Italian, Dutch, Greek, Norwegian, Polish, French and German liners.



Probably from the Russian meteorological spacecraft, Meteor 12, this photograph was received at the Department of Electrical Engineering and Electronics, University of Dundee. Transmission frequency is 137.62MHz, a.m. subcarrier frequency is about 2.58kHz and the f.m. deviation of the r.f. carrier is about ± 18kHz. The line scan rate is 120 per minute. The track of the spacecraft is in a near polar orbit at a height of 900km with a period of 102.95 mins and the track is repeated exactly on alternate days but about 10 mins earlier each time. Transmissions are on alternate days only.

Electronic ignition for 1973 cars

Chrysler Corporation has ordered three million power transistors from the RCA Solid State Division, Somerville, New Jersey, for use in electronic ignition systems of the 1973 Chrysler, Plymouth and Dodge model cars. Chrysler introduced electronic ignition on a limited number of imperials in the 1971 models after spending several years perfecting the ignition design. According to Chrysler, electronic ignition offers two major advantages to the car owner. First, it minimizes timing problems and improves engine efficiency. The owner, therefore, achieves better engine performance and mileage. Second, through improved engine efficiency, exhaust emission is cleaner.

The electronic ignition system generates a standard spark, but timing is improved significantly. Higher voltage operation means that spark plugs need be changed less frequently and engine tune-ups should be necessary only about every 50,000 miles if the car burns low lead petrol.

Faraday lectures

"Navigation — land, sea, air and space" has been chosen as the subject of the 44th in the series of Faraday lectures, open to the general public, and organized by the Institution of Electrical Engineers. Dr. Andrew Stratton, director of the Defence Operational Analysis Establishment, together with his deputy lecturer Wing Commander E. W. Anderson, navigational adviser of Smiths Industries, will be lecturing on navigation in 12 different centres in England, Scotland and Wales between November 1972 and April 1973. They will tell the story of the development of navigation from the days when the stars were our only guide to the sophisticated instruments of today which have helped to make it possible for man to reach the moon. Tour details are given in a programme available from I.E.E., Savoy Place, London WC2R 0BL.

November Meetings

LONDON

1st. IEE — "Fifty years of British broadcasting — a survey of the technology" by J. Redmond (chairman, Electronics Division) at 17.30 at Savoy Pl., WC2.

1st. IERE — "Electronic aspects of civil submersible operations" by Capt. K. A. Goudge at 18.00 at 8-9 Bedford Sq., WC1.

2nd. IEE — "High energy particles in space", eighth Appleton lecture by Prof. H. Elliot at 17.30 at Savoy Pl., WC2.

3rd. IEE/RSGB — "The first five years of wireless, 1896-1901" by G. R. M. Garratt at 17.30 at Savoy Pl., WC2.

6th. IEE — Colloquium on "Band II v.h.f./f.m. reception, including stereo demultiplexing" at 10.00 at Savoy Pl., WC2.

8th. IEE — "Transmitter output valve developments above and below 30MHz" by R. G. Roach at 17.30 at Savoy Pl., WC2.

8th. IERE — "Development and production management through electronic data processing" by J. A. Freer at 18.00 at 8-9 Bedford Sq., WC1.

9th. RTS — "Broadcast cassette recorders" by P. Dare and M. Salter at 19.00 at I.B.A., 70 Brompton Rd, SW3.

10th. IEE — Symposium on "Broadcasting engineering" at 10.00 at Savoy Pl., WC2.

13th. IEE — "The development of the television camera tube" by W. E. Turk at 17.30 at Savoy Pl., WC2.

13th. I.Mech.E. — "Use and development of electronics in Locomotive control systems" by R. Wilson and R. M. Bradley at 17.30 at 1 Birdcage Walk, SW10.

13th. IEETE — "Global telecommunications in the space age" by E. Fennessy at 18.00 at the IEE, Savoy Pl., WC2.

14th. IEE — "The BBC in the 80s — the relationship between broadcast policy, programme needs and technological potential" by C. J. Curran, director-general. B.B.C. at 17.00 at Savoy Pl., WC2.

15th. R.I. Navigation — "Long haul airlines and satellite communications" by J. O. Clark at 17.00 at the Royal Inst. of Naval Architects, 10 Upper Belgrave St, SW1.

20th. IEE — "R.F. attenuation standards" by R. W. Yell at 17.30 at Savoy Pl., WC2.

22nd. IERE — "What's new in multilayer printed wiring board manufacture" by G. C. Wilson at 18.00 at 8-9 Bedford Sq., WC1.

23rd. RTS — "A further look at colour receiver servicing" by B. A. Barnard and J. Harris at 19.00 at I.B.A., 70 Brompton Rd, SW3.

27th. IEE — Colloquium on "Novel types of transducers" at 14.30 at Savoy Pl.. WC2.

28th. IEE/I.Mech.E. — "Active attitude control of spacecraft' by Dr. W. G. Hughes at 17.30 at Savoy Pl., WC2.

29th. IERE — "Improving the efficiency of multiplex operation of integral cavity klystrons by using a simple i.f. predistortion circuit" by J. E. Burrows at 18.00 at 8-9 Bedford Sq., WC1.

BELFAST

21st. IEE/IERE — Lecture by J. Redmond to commemorate the 50th anniversary of broadcasting in the U.K. at 18.30 at Queen's University.

BIRMINGHAM

8th. RTS — "Special effects" by Mike Cox at 19.00 at A.T.V. Centre, Broad St.

BRIGHTON

7th. IEE Grads — "Recent developments in radio astronomy" by Dr. H. G. Muller at 19.30 at the University of Sussex, Falmer.

BRISTOL

23rd. IEE — Faraday Lecture — "Navigating — land, sea, air and space" by A. Stratton at 18.30 at Colston Hall.

29th. IEE/IERE — "Future aspects of broadcasting in Europe" by Dr. F. T. Von Rautenfeld of the European Broadcasting Union at 18.00 at The University.

CAMBRIDGE

9th. IEE — "Advances in marine navigational aids" by F. M. Foley at 18.30 at The University Engineering Dept., Trumpington St.

23rd. IEE/IERE — "Semiconductor progress — past, present and future" by E. Wadden at 18.30 at The University Engineering Labs., Trumpington St.

CARDIFF

1st. SERT — "The development and manufacture of magnetic tape" by F. Fielding at 19.30 at Llandaff College of Technology.

8th. IERE — "Video recording" by D. Jeffery at 18.30 at the University of Wales Institute of Science and Technology.

CHATHAM

2nd. IERE — "Developments in colour television cameras" by P. W. Loose at 19.00 at Medway College of Technology.

30th. IERE — "Yacht electronics" by N. T. J. Bevan at 19.00 at Medway College of Technology.

CHELMSFORD

1st. IERE — "Playback radar" by J. Watts at 18.30 at The Civic Centre.

9th. IERE — "Radio astronomy telescopes" by R. Levente at 19.30 at The Hoffman Lecture Theatre.

CHELTENHAM

23rd. IEE/IERE — "Electronics in crime detection" by A. T. Torlesse at 19.30 at G.C.H.Q. Club, Oakley.

COVENTRY

22nd. IERE — "Modern trends in industrial telemetry" by D. J. Barker at 19.15 at Lanchester Polytechnic, Priory St.

DAGENHAM

23rd. IEE — "Recent advances in digital communications" by Prof. K. W. Cattermole at 18.30 at the N.E. London Polytechnic. Barking Precinct, Longbridge Road.

DUBLIN

13th. I.Eng.Ireland — "The history of the development of the electronic organ" by T. D. Towers at 20.00 at the Burlington Hotel.

DURHAM

22nd. IEETE — "Technician engineers and technicians — their education, training, role and status, at home and overseas" by E. A. Broomfield at 19.30 at Science Site Laboratories, South Rd, Durham University.

FARNBOROUGH, Hants

16th. IERE — "Electronics in crime detection" by A. T. Torlesse at 19.00 at the Technical College.

GLASGOW

17th. SERT — "Amateur radio" by T. Hughes at 19.30 at the YMCA Club, 100 Bothwell St.

HULL

30th. IEE — "Application of a phase-locked loop to a stereo decoder" by A. J. Haywood & T. Portus at 18.30 at YEB Offices.

LINCOLN

9th. SERT — "Colour television" by K. J. Bohiman at 19.30 at Lincoln College of Technology, Cathedral St.

LIVERPOOL

8th. IERE — "On-line digital adaptive control" by Dr. D. J. Sandoz at 19.00 at the University Dept. of Electrical Engineering and Electronics.

LOUGHBOROUGH

8th. IEE/IERE — "Progress in broadcasting engineering" by A. V. Lord at 19.00 at Edward Herbert Building, Loughborough University.

MAIDSTONE

6th. IEE — "Ionosphere and radio engineering" by G. Millington at 19.00 at the Royal Star Hotel.

8th. IEETE — "University-industry collaboration in instrumentation research and development" by Dr. G. F. Reynolds at 19.30 at University of Reading

MANCHESTER

16th. IERE — "Television colour studio techniques" by R. Nether at 18.15 at Renold Building, UMIST.

MIDDLESBROUGH

28th. SERT — "I.C. model control" by R. Heath at 19.30 at the Cleveland Scientific Institution.

NEWCASTLE-UPON-TYNE

1st. SERT — "Electronics in precision optical measurement" by D. Dawson at 19.15 at the Charles Trevelyan Technical College, Maple Terrace.

6th. IEE/IERE — "Local radio broadcasting" by T. Gordon and D. Gill at 18.30 at the University.

8th. IERE — "Computer graphics and the common man" by B. S. Walker at 18.00 at Ellison Building, Newcastle-upon-Tyne Polytechnic.

NEWPORT, I.o.W.

10th. IERE — "Active filters — a summary of current digital and analogue techniques" by Dr. D. R. Wilson at 19.00 at the Technical College.

PLYMOUTH

9th. IEE/IERE — "Pulse code modulation as applied to broadcasting" by Dr. C. J. Dalton at 19.00 at The Polytechnic.

PORTSMOUTH

1st. IEE/IERE — "Generation of random signals in electrical engineering" by D. Hampshire at 18.30 at The Polytechnic.

14th. IEE Grads — "Making electronic music" by G. Rogers at 19.30 at Pendragon Hotel.

29th. IERE/IEE — "Electronics in schools" by R. J. Stephenson at 18.30 at The Polytechnic.

READING

9th. IERE — "Design of low-distortion class B amplifiers" by P. F. Blomley at 19.30 at The J. J. Thomson Physical Laboratory, Whiteknights Park.

SHEFFIELD

20th. IEE — "The Prospero satellite" by H. J. H. Sketch at 19.30 at The University.

22nd. IEE/IERE — "Development of digital sound and television systems with emphasis on recording" by A. H. Jones and F. A. Bells at 18.30 at The University.

SOUTHAMPTON

22nd. IEE/IERE — "Synthesis and testing of logic systems" by Prof. D. W. Lewin at 18.30 at the Lanchester Theatre, The University.

SWANSEA

21st. IEE — Faraday Lecture — "Navigating — land, sea, air and space" by A. Stratton at 18.30 at Brangwyn Hall.

WELLINGBOROUGH

15th. SERT — "The registration of technician engineers and technicians" by A. J. Kenward at 19.30 at the Lecture Theatre, Wellingborough Technical College, Church St.

Doppler Radar with Sense

Portable radar showing movement direction sense and speed

*by K. Holford**

Possible uses for Doppler radar range from measuring speeds of automatically controlled mechanical equipment to the docking of large tankers. Large tankers approach the dock at 2 metres per minute, and at that speed it is difficult to discern movement visually let alone distinguish the direction. Later on in this article a radar suitable for this purpose will be described, but as a preliminary the reader might appreciate a simple exposition of how Doppler radar works and what is required to extend existing ideas to provide the direction sense information.

The simple microwave Doppler radar speed-measuring equipment which uses just the Doppler beat rate cannot tell whether the moving object is approaching or receding. This sensing can be done using more than one detector but results in a microwave circuit which until recently has been too cumbersome and expensive, except for the few applications which demand it.

However, it is now possible to print almost the whole of the microwave part of a 'Doppler radar with sense' on a 46mm square alumina† substrate as shown in Fig. 1. The cost of such an integrated circuit will depend upon the quantities produced, but even a short production run should reduce it to half that of the waveguide version, and so perhaps the time is now ripe to look towards applications in which direction indication as well as velocity measurement is of particular advantage.

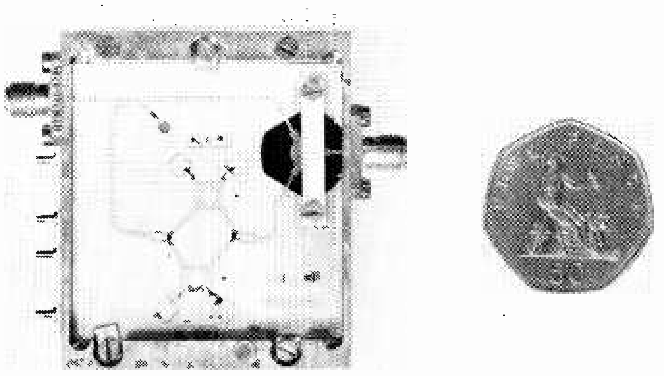


Fig. 1. An X-band microwave integrated circuit front-end for Doppler radars having direction sense. The m.i.c. contains a circulator and two balanced mixers.

Operating principles of Doppler radar

One of the simplest radars without sense, uses two small horn aerials as shown in Fig. 2. This arrangement forms the basis of many intruder alarms. It uses a microwave generator providing typically 5mW output. This would now normally be a semiconductor type with 7V 120mA power supply and called a Gunn source after the discoverer of the effect. Gunn sources are available in coaxial or waveguide constructions, the coaxial type usually being less prone to spurious oscillation modes but having the poorer frequency stability of the two.

The microwave power is fed from the Gunn cavity along a coaxial cable and enters the horn H_1 where the exposed part radiates an electromagnetic field. This radiation is in the form of a beam, the size of which depends upon the horn aperture, but is usually 25 to 60° wide, the horns being typically 8cm across when using the frequency (10.687GHz) allocated for intruder alarms. Ideally the field varies sinusoidally (since if it does not there must be other frequencies radiating) and propagates at the speed of light, 3×10^8 metres per second.

The waveforms shown are a simplified time-frozen picture of the field intensity versus distance along the lines shown, except that the power reflected to the aerial H_2 from target X is much smaller than the size of the waves might indicate. The field in H_2 is coupled from the waveguide by probe P_1 and applied to diode D.

A single aerial can be used for both transmit and receive but this normally involves a non-reciprocal isolating device such as a circulator.

Adding mixer r.f. bias to get a Doppler output

To get a Doppler signal from D, rather than just the detected W_1 signal, requires that the diode also be supplied with some microwave power directly from the microwave genera-

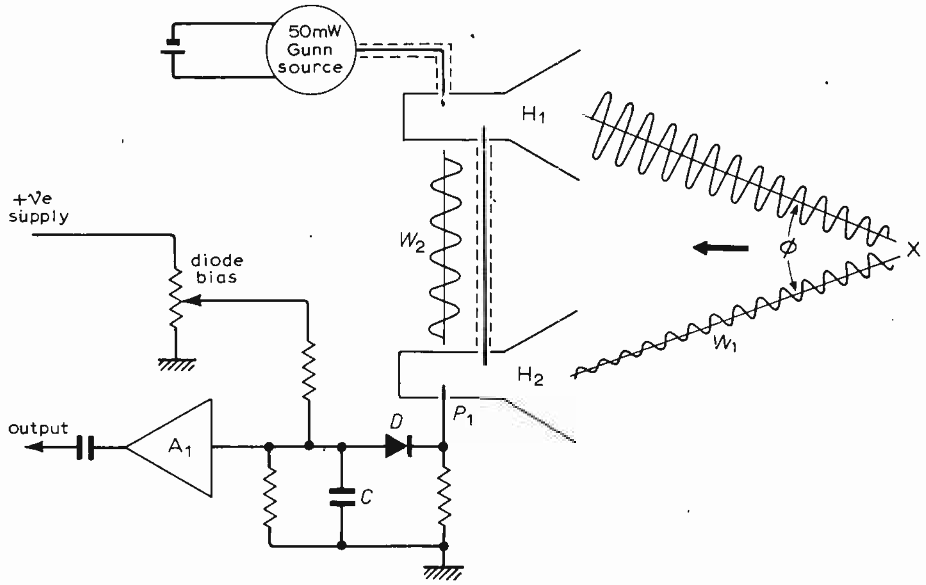


Fig. 2. A simple Doppler radar.

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*Mullard Research Laboratories, Redhill.

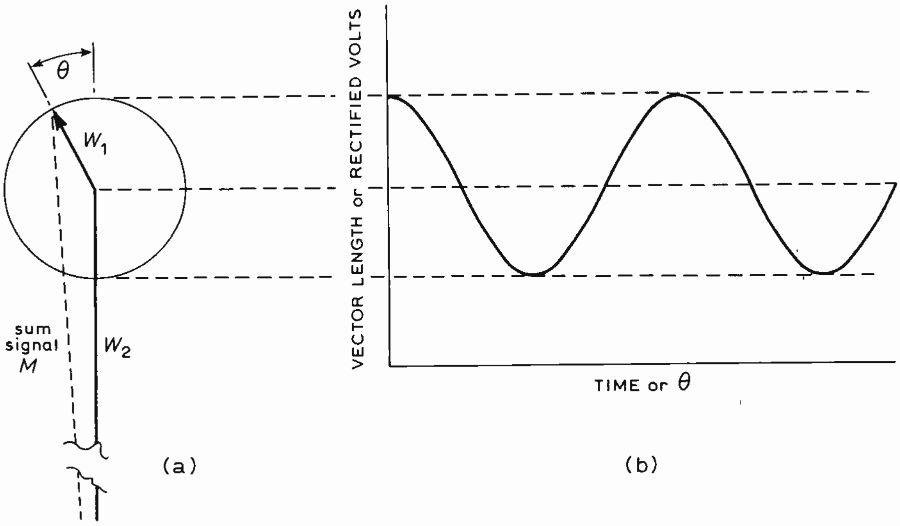
†An aluminium oxide which looks rather like opal glass.

tor and this is indicated by the wave W_2, flowing along the wire which has 'aerial' probes in both guides. The power of W_2 is typically 0.5mW, and turns out to be much larger than a normal return from a target, but even so is an amount of signal which brings the diode D to its best sensitivity as a mixer.

The two signals W_1 and W_2 are added together and the diode D detects the sum signal and produces a direct output voltage accordingly. The phase relationship between the two waves is important because W_1 could either add to or subtract from W_2. The point to notice about the wave diagram is that, although the fields are moving out and back at 3×10^8 metres per second, and so the field is everywhere changing sinusoidally with time, the two wave trains W_1 and W_2 have a fixed phase relationship at the mixer diode D, provided the target is stationary. This phase relationship changes with target movement as more or fewer waves fit into the round trip path from the radar to the target and back to the radar at H_2. Thus if X moves continuously the diode D will produce a varying amplitude direct voltage across capacitor C, the value at any instant depending upon whether the signal returned from the target is adding to or subtracting from the much larger signal arriving along path W_2.

Calculation of Doppler frequency

Taking the larger signal as a phase reference, the target-return signal W_1 must be added to it on a vector basis and this is shown in Fig. 3(a). As a starting point the small vector W_1 is given a phase of θ relative to W_2. This phase changes as the target moves, and W_1 rotates one complete revolution each time the round trip path changes by one wavelength. The voltage applied to the diode is the sum signal M.



(a)

(b)

Fig. 3. (a) Vector addition of mixer signal W_2 and target return W_1. (b) Change of length with time of θ change. (Note that in practice $W_2 \gg W_1$.)

If the target moves at a steady rate, so that W_1 rotates at a fixed rate, the length of the sum vector M changes sinusoidally with time as shown in Fig. 3(b). In practice W_1 is much smaller than W_2 and the sinusoidal variation in vector length is transferred fairly faithfully to detected d.c.

The d.c. part of the rectified signal is of little interest and so in practice a high-gain a.c. amplifier is used to amplify just the perturbations. Such a signal is known as the Doppler signal because of its similarity to the acoustic Doppler effect such as the change in pitch of a train whistle associated with passing trains. To understand this it is necessary to view the system slightly differently and to observe that a target movement increases or decreases the number of waves in the round trip path. Thus, viewing the received signal from the position of H_2, in Fig. 2, the return signal is *seen to be* of a lower or higher frequency than that radiated from H_1, according to whether the target lets extra waves slip into the path or squeezes them out.

The Doppler frequency is now easily calculated. Angle ϕ is usually small enough to be considered zero because the target range is usually much larger than the spacing between H_1 and H_2. Thus each time X moves by one half wavelength in the direction of the arrow it takes a half wavelength out of each path and there is one wavelength less in the round-trip path. If the velocity of movement is v metres per second there will be a change in wavelength of $2v/\lambda$ per second, where λ is the wavelength. The Doppler shift is therefore

$$f = 2\,v/\lambda \text{ Hz}$$

Since the propagation speed of electromagnetic waves is 3×10^8 metres per second, λ becomes $3 \times 10^8/F$, where F is the microwave frequency. Thus the Doppler frequency is given by

$$f = 2\,vF/(3 \times 10^8) \text{ Hz}$$

Taking the allocated intruder alarm frequency of $F = 10.687$ GHz and a target speed of 1 m.p.h. (0.45 metres per second) this gives the Doppler frequency f, as 31.8Hz.

So much for a simple Doppler radar operating in the X-band (7.5 to 12 GHz). As microwave apparatus goes it is fairly cheap and easy to set up.

The mixing signal W_2 is not very critical and in most applications a total radiated power of 5mW is enough to provide a useful detection sensitivity and is within the 10mW limit specified with the frequency allocation. When used in an enclosed room, however, there is not usually a radio interference risk.

Measuring direction sense

The simple Doppler radar can be used for many movement measuring and monitoring applications, but it cannot indicate the direction of movement because a receding target produces the same sort of signal as an approaching one. However, the direction information can be got if a second detector is used, provided this is placed at a suitably different position. This is shown in

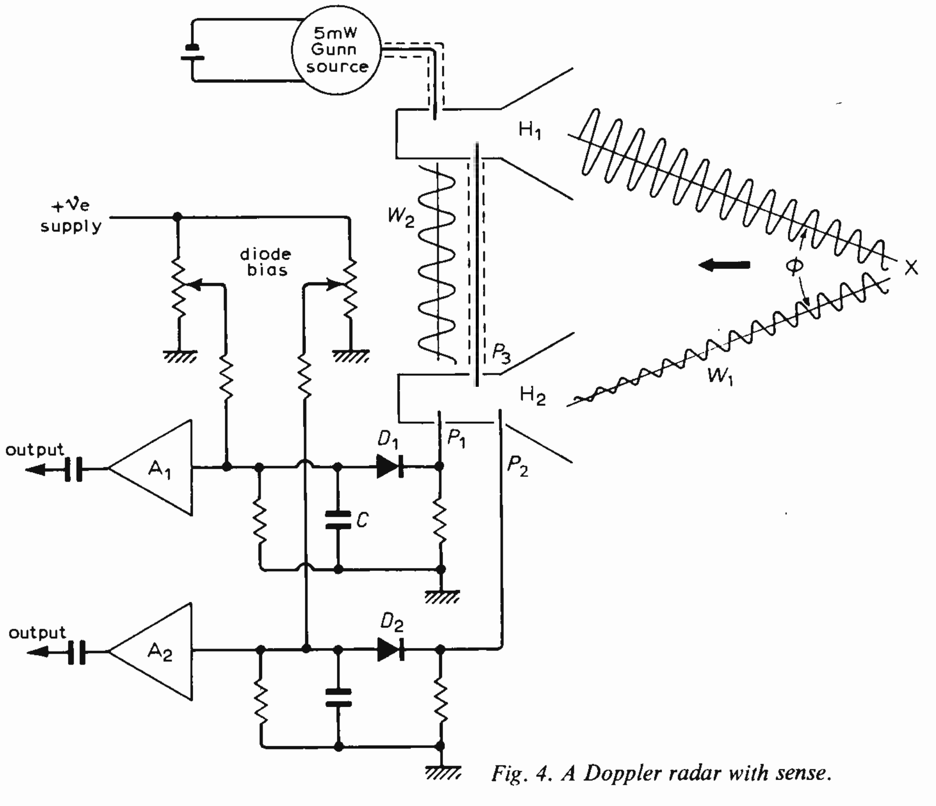


Fig. 4. A Doppler radar with sense.

Fig. 4 where the second probe P_2 is upstream by a suitable part of a wavelength distance.

To simplify matters consider that the spacing of the probes is such that both P_1 and P_2 receive the same phase of P_3 signal and that P_2 is a quarter-wave (90° phase) distance up-stream from P_1. When target X moves towards the radar and passes through the position which makes the waves W_1 and W_2 sum to a maximum at P_2, the maximum at P_1 is about to occur a little later when the W_1 path length has shortened by another quarter wavelength. In other words the Doppler amplitude modulation of the sum signal at P_1 lags P_2 by a quarter wavelength (90°), where the wavelength is being measured at microwave frequency, but the Doppler is normally being produced at audio frequency. If the target is now considered for the case where it is moving away from the radar, then the maximum at P_2 follows a quarter wavelength behind the maximum at P_1. These phase relationships are shown in Fig. 5 in which the wave from P_2 (A_2) is used as the reference wave.

The choice of a probe spacing of quarter wavelength can now be seen to be very convenient, because when A_2 is crossing zero, in say the positive-going direction, the sign of the A_1 wave indicates the target direction. But A_1 is also sitting nicely equally each side of the A_2 zero and so allows maximum circuit errors before any logic would give a wrong answer. One way of processing the signals would be to use the A_2 wave to produce a pulse or edge each time it crossed zero in the positive-going direction, for instance using a Schmitt trigger which triggered each time the wave became minutely positive. This pulse can then be applied to a circuit which has the output polarity controlled by the sign of the A_1 signal. Such a circuit is shown in Fig. 6. The A_1 waveform controls which of the Tr_2 or Tr_3 transistors conducts, but neither can conduct except during the time that Tr_1 is turned on by the pulse which is applied to input (1). The A_1 wave controls the Tr_2–Tr_3 pair, by making one of the two bases, b_1 or b_2 more positive than the other during the time that Tr_1 conducts, and so determines which of the two resistors, R_1 and R_2 has voltage developed across it. This voltage causes the appropriate Tr_4 or Tr_5 transistor to conduct and so causes meter M to deflect left or right.

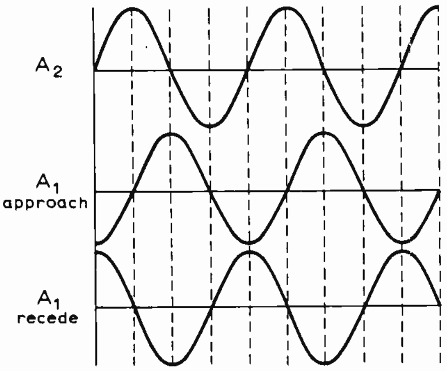


Fig. 5. Phase relationship between A_1 and A_2 for (1) an approaching target and (2) a receding one.

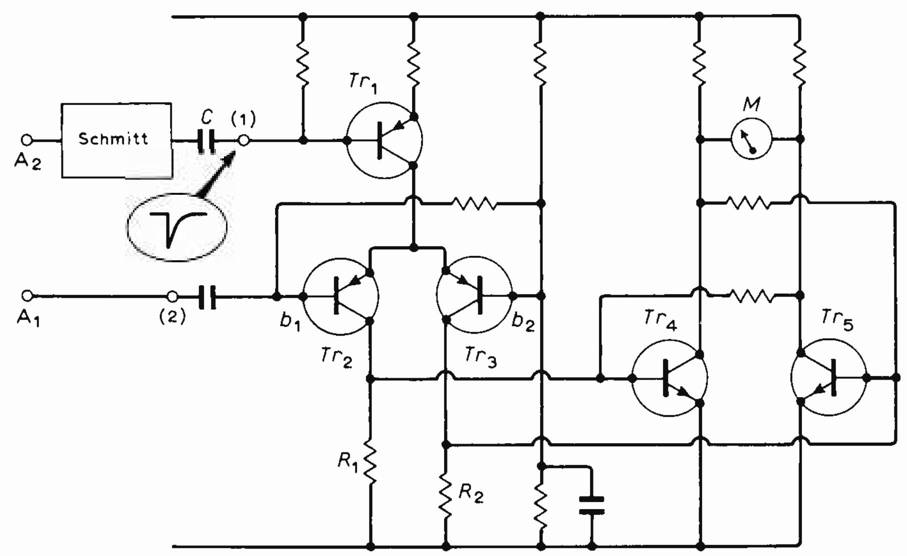


Fig. 6. Type of circuit which will indicate sense.

Ideally no further change in M occurs after the first setting unless the phase relationship between A_1 and A_2 changes due to a change in target direction.

Although the above circuit contains the basic workings of a system and can be developed, it is hardly worth doing so since integrated circuits can be found which will do the complete job and decode the A_1, A_2 waves if they are connected to the appropriate terminals.

Combating noise from the microwave source

One other aspect of Doppler radar needs describing before an engineered arrangement can be considered, and that is to do with noise. Since the larger part of the signal received by the diodes is supplied directly from the microwave generator, any noise from this can have a very significant effect on performance. With a short range radar the noise amplitude variations will be more important than frequency changes. The amplitude noise will be detected and in a simple system is largely indistinguishable from a target signal of similar strength. This can set the limit to the sensitivity of a radar and therefore its ultimate usefulness. The effect of this noise can be reduced by about a factor ten in voltage terms, at the expense of doubling the number of diodes used, and the principle is demonstrated using the probe arrangement in Fig. 7.

It is assumed that the probe arrangement is such that probe P_3 delivers equal power at the same phase to both P_{1a} and P_{1b}. Since P_{1a} is a half wavelength down-stream from the target, compared to P_{1b}, the Doppler signals produced by these two probes will be 180° out of phase; because a moving target, which is, say, approaching, will produce a peak signal amplitude at P_{1a} a half wavelength later than it produces it at P_{1b}. For a receding target, similar phase relationships occur again because a Doppler delayed by 180° looks similar to the previous one which was advanced 180°, there being 360° between the two which is just one cycle of Doppler difference.

The two antiphase Doppler signals produced by diodes D_{1a} and D_{1b} can be summed to give a double strength signal by applying them simultaneously to a differential input amplifier which inverts the signal applied to one of its inputs (A_{12}, Fig. 7).

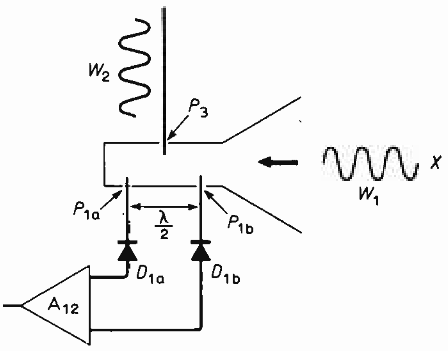


Fig. 7. Amplitude-modulation noise rejection using a pair of diodes.

This type of amplifier rejects signals that are of the same amplitude and polarity by the common mode rejection capability. And it will now be shown that amplitude noise on the mixing signal W_2 has the same effect on both P_{1a} and P_{1b}. The amplitude noise to be rejected is caused by low-frequency variations in amplitude of the microwave signal supplied directly as W_2. Since it is mainly in the audio frequency range, there must be many hundreds of thousands or even millions of cycles of microwave frequency between each noise peak. And since the W_2 signal supplied to the two probes P_{1a} and P_{1b} differs by only a fraction of a cycle in the arrangement shown in Fig. 7, or perhaps a few cycles in some arrangements, it follows that both D_{1a} and D_{1b} receive the amplitude variations, for all practical purposes, at the same time. Thus D_{1a} and D_{1b} will produce the same phase and amplitude of noise signal provided they are supplied with the same amount of W_2 signal, and are matched diodes. (The amount of W_2 signal could be adjusted to take account of the different diode sensitivities but in practice it is often easier to choose matching diodes.) Having both diodes the same way round is very convenient for portable equipment because only a single polarity battery supply is required for diode d.c. bias. However, it is also possible to get noise rejection by reversing one of the diodes and using a single input amplifier. The noise currents then subtract, but the two Doppler signals are of the same phase and constitute a combined power signal by virtue of their lower impedance signal source. This has previously been the more common arrangement, but there seems to be no great difficulty in using the differential A_{12} arrangement in Fig. 7.

The f.m. noise becomes significant if the radar is receiving signals from (stationary) unwanted targets which are stronger than the wanted signal, provided the receiving distance is sufficient. The mixer then receives two 'frequency' different signals due to the time delay and the frequency shifting nature of the microwave source. As far as is possible this should be avoided. Additional cavities can be added to a microwave source to reduce f.m. noise provided the expense is justified.

Radar construction

Engineering a radar with multiple probes presents problems, because if the probes are individually designed to extract as much signal as possible by having good coupling into the waveguide, they interact. However, to use less coupling means a loss of efficiency. Thus in practice a better engineered power-splitting arrangement is preferred. This can be done in waveguide construction but it is expensive and bulky. One radar at present in use has about a cubic foot of metal waveguide components, as well as the aerial, and this arrangement is hardly portable.

Printing the microwave circuit

It is possible to print most of the microwave circuit in the form of interconnected thin film transmission lines etc., using nichrome and gold and a 46mm square alumina substrate as shown in Fig. 1. This has a double diode balanced mixer for each Doppler output to reject oscillator noise as just described. Each pair of diodes is connected to a transmission line ring known as a hybrid ring and the path length differences required to produce the correct Doppler phase are built in. The signal path and the mixer path lengths are both used, since adding length to one path has a similar effect to shortening the other, as far a achieving a particular phase difference is concerned. The width of the conductor is varied to get the desired power splitting ratio and this is particularly noticeable for the rings.

Microwave i.c. in tanker docking radar

The microwave integrated circuit (m.i.c.) shown in Fig. 1 includes a circulator which enables the use of a single aerial for both transmission and reception. A block diagram of a Doppler radar, with direction sense, using this m.i.c. is shown in Fig. 8. The circulator is a power routing device having non-reciprocal properties based upon current flow over a polarized magnetic material. Microwave power entering port 1 flows out of port 2, except for reflections due to aerial impedance mismatch and leakage due to device imperfections. Power entering port 2, including the reflection, is routed to port 3. Reflected power is typically held to less than 4% at which it is small enough not to alter substantially the diode microwave "bias" signal (W_2 in previous figures) or upset the working of the Gunn oscillator which tends to be sensitive to reflected power greater than about 4% (1.5:1 v.s.w.r.).

It is beyond the scope of this article to go into greater detail in describing the design of the m.i.c. and the system, but the device can be assumed to produce the two phase-related Doppler signals as required which are individually amplified in the A_1 and the A_2 channels. The phase detector has already been described, leaving the speed meter and audio monitoring to be covered.

Speed meter

A suitable speed meter which could be used with this or any other Doppler radar is shown in Fig. 9, and is based upon generating pulses of fixed height and width, one or two, for each Doppler cycle. The circuit is a monostable and the average voltage across the 10kΩ collector load of Tr_1 is proportional to the number of pulses per second, i.e. proportional to speed. The input trigger pulses must be shorter than the length of the output pulses, which in turn is controlled by the value of C. The pulse length must also be about 5% or more shorter than half the repetition time at the highest intended speed, if ambiguity is to be avoided with off-scale input frequencies.

Audio monitor

The audio monitor presents a problem when the Doppler frequency is very low, because of the difficulty in making this frequency audible. For the tanker docking radar the Doppler frequency ranges from approximately 1 kHz to 1 Hz. The latter corresponds to a movement speed of 1 metre per minute, and even lower speeds could be monitored if the direction sense is not important. The solutions considered included modulating the audio onto a carrier such as 1 kHz, either as f.m. or a.m. but this became indistinct at the higher audio frequencies. The solution adopted was to generate 0.2ms pulses, one for each half cycle of the Doppler. Thus at low frequencies clicks are emitted, but these blend and change to a tone as the speed increases. The scheme works well over the complete range and the note at higher speeds is not all that different from a normal clipped Doppler wave which would be given by the Doppler amplifiers directly.

The complete radar

A picture of the prototype tanker docking radar is shown in Fig. 10. It is a low power X-band c.w. Doppler radar able to measure

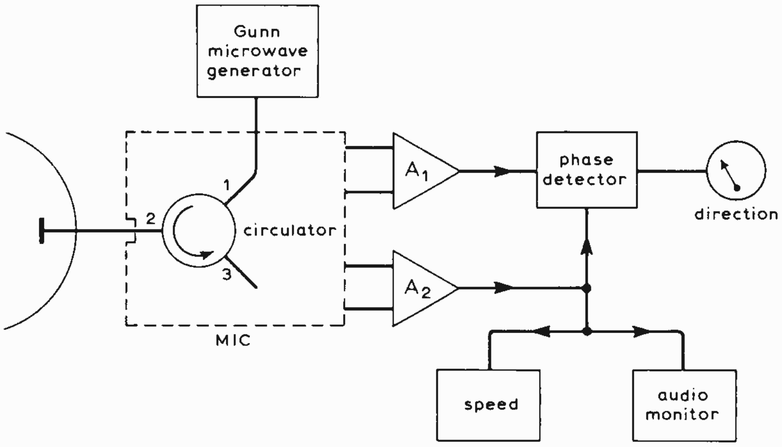
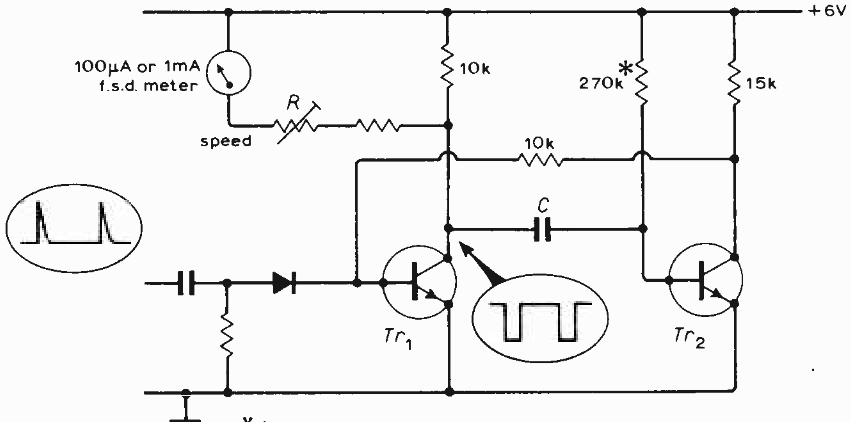


Fig. 8. Block diagram of Doppler radar with sense using Mullard m.i.c.



*$h_{FE} \leqslant 150$ for Tr_2 for easy triggering by input signal

Fig. 9. Speed/frequency meter based upon a monostable.

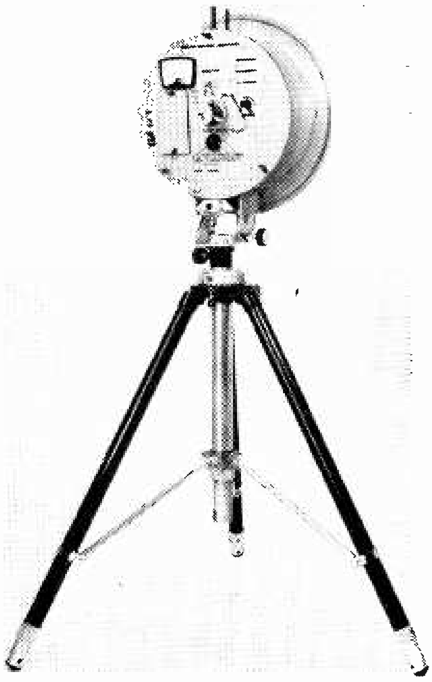


Fig. 10. Prototype tanker docking radar.

both the speed of an approaching ship (over the range 1 yd per minute up to 30 knots) together with the sense of movement i.e. approach or recede. The sense indicator is useful for aiming the radar. The fluctuations of the direction meter pointer due to noise begin to change their pattern when a weak target enters the radar beam and before it is strong enough to give a speed reading. It also shows that a good target signal had been acquired. An audio signal is also provided for these preferring to monitor the radar aurally. The audio pitch changes smoothly speed and works over the total speed range. At the lower speed the tone becomes a series of clicks.

Optimal automatic protection of the speed meter against false readings with weak signals has been provided; the speed meter can be switched to read only when a single, clear signal is present. The range of the equipment depends upon the type of target, the amount of microwave power radiated and the size of the aerial dish. The demonstration model radiates 6mW of power and should be usable to detect most vessels of 80ft (24 metres) or more in length at 1 mile, and a larger tanker at $1\frac{1}{2}$ miles. Used on land it can indicate the speed of most cars and lorries at about 300 yards. With a smaller aerial the equipment might be useful in the automation of machine control.

The equipment can be mains or battery powered and has a built in rechargeable battery which provides 4 to 5 hours continuous use. Total current consumption is only about 0.2A.

Acknowledgement

The m.i.c. referred to in this article was designed by Mr. L. W. Chua. There have also been useful discussions with Dr. P. Bulman, of R.R.E.

Books Received

Electronic Circuits Manual by John Markus contains an enormous array of clearly illustrated and labelled circuits arranged in 99 chapters. Engineers, experimenters, hobbyists and students alike will appreciate this compendium of over 3,100 circuit designs, each complete with component values. This quick-reference manual, which has been organized and indexed for efficient retrieval of circuits and circuit data, was compiled by the author of an earlier manual "Sourcebook of Electronic Circuits" and will be of primary interest to all those involved with the design, development and testing of electronic circuits.

Similar circuits are grouped together for ease of comparison and in addition to the actual circuit with its relevant design and performance data, each entry includes an abstract (which presents the drawbacks, as well as the advantages) for each circuit, and reference to the original article, book, report or other source from which more information can be obtained, if desired. The circuits used reflect the widespread use of integrated circuitry and solid-state components. However, the author has not neglected to include valve circuits still being used because they can handle higher power and perform electronic jobs for which transistors either have not yet been developed or have not proved satisfactory. All circuits may be used exactly as shown, but suggestions are often given for modifications to meet other performance requirements.

Among the chapters not included in the predecessor "Sourcebook" volume are those covering circuits for audio control, automotive control, automotive ignition, high voltage, lamp control, lamp dimmer, lasers, magnetic tape, metal detection, operational amplifiers, opto-electronics, power supply protection, single-sideband tachometer, telephone, triangular-wave generator, voltage controlled oscillator, voltage level detector, voltage reference and zero-voltage detector circuits. In the chapter on lasers there are 13 circuits and in that on op-amps there are 115 practical applications. Pp. 988. Price £9.50. McGraw Hill Book Company, Shoppenhangers Road, Maidenhead, Berks.

Semiconductor Data Library is a three-volume set of data books for identifying and selecting the most appropriate semiconductor devices from the current range of Motorola products. Volume 1 covers type numbers up to 1N4999 and up to 2N4999, while volume 2 deals with types from 1N5000 and 2N5000. Data sheets are in numerical sequence according to device type number except for those data sheets that cover several devices with differing type numbers. A numerical index provided at the front of each of these volumes permits the user to quickly locate the page number. Volume 2 will be up-dated through the publication of supplements — two will be published during the life of this edition. A third volume contains a master index, selection guides, outline drawings with hardware, packaging and application abstract information. The price of the set is £5.90 but free copies will be presented to customers of Jermyn distribution division who place orders for Motorola descrete devices worth £250 or more. Motorola Semiconductors Ltd, York House, Empire Way, Wembley, Middlesex.

Amateur Radio Techniques by Pat Hawker G3VA is aimed at extending the reader's awareness of new devices and techniques and providing a sourcebook for many useful circuits and aerials. This fourth edition has been substantially enlarged and contains over 600 diagrams with new material and features having more emphasis on integrated circuits, a "quick guide to digital electronics" and much additional information on aerials and the cure of TV interference. Chapter topics include semiconductors, components and construction, receiver, aerial, oscillator and transmitter topics, audio and modulation, power supplies, fault finding and test units. Also included is a list of i.f. alignment for the majority of receivers likely to be encountered, including British, American, Japanese, Continental and ex-Government receivers. Pp 256. Price £1.60 plus 20p post and packing. Radio Society of Great Britain. 35 Doughty Street, London WC1N 2AE.

The first two volumes of a new series of illustrated engineering publications under the general title of **"I.B.A. Technical Review"** have been published by the Independent Broadcasting Authority. Two new titles in the series will be published each year.

The contents of Volume 1, **"Measurement and Control"**, include 6 papers: Some methods of automatic analysis of television test signals; Experiments with a computer in a television control and monitoring centre; Off-air reception measurement at proposed sites for u.h.f. television relay stations; Television studio performance measurements; A new equipment for the measurement of video noise; and Computer-aided programme presentation.

Volume 2, **"Technical Reference Book"**, includes: Specification of television standards for 625-line System I transmissions; Code of practice for studio centre performance; Code of practice for the technical performance of I.B.A. transmitting stations; Specification of audio distortion measurements, Programme technical quality assessments and reporting procedure; I.B.A. transmitting stations; and Code of practice for Independent Local Radio studio performance.

The books are being produced for British and overseas professional broadcasting engineers. Free copies can be obtained from I.B.A., Engineering Information Services, 70 Brompton Road, London SW3 1EY.

Operational Amplifiers is prepared and edited by the applications and engineering staff of the Burr-Brown Research Corporation. It is in two sections, part 1 of which considers in detail, some of the factors which influence the design technique and methods now becoming the essential tools of the linear circuit designer. It deals progressively with the development of op-amps from the characterization of bipolar and field-effect transistors through to the design of the individual and complete multistage operation amplifiers. It outlines the techniques available for the control of elements which determine amplifier performance characteristics and limitations. Part 2 is an extensive discussion of current applications with sufficient circuit descriptions to permit design adaptation and extension. Linear and non-linear circuits, multiplier/dividers, A/D conversion, active filters, signal generation, modulation and demodulation techniques are dealt with, inclusive of error factor analysis. Progressive development has been used, the work terminating with an appendix presenting the results of fundamental circuit theory with test methods and definitions for parameter evaluation. Pp. 468. Price £7.20. McGraw-Hill Book Company, 34 Dover Street, London W1.

Circuit Ideas

Voltage-controlled triangle generator

In the February issue H. Macdonald gave a circuit for a triangular-wave generator (Circuit Ideas, page 77). Here is a simpler circuit which is also a frequency-to-voltage converter. Excellent square and triangular waves are formed which may be used to produce sine waves by diode or f.e.t. shaping.

The circuit was designed to meet the following requirements for a specific application.

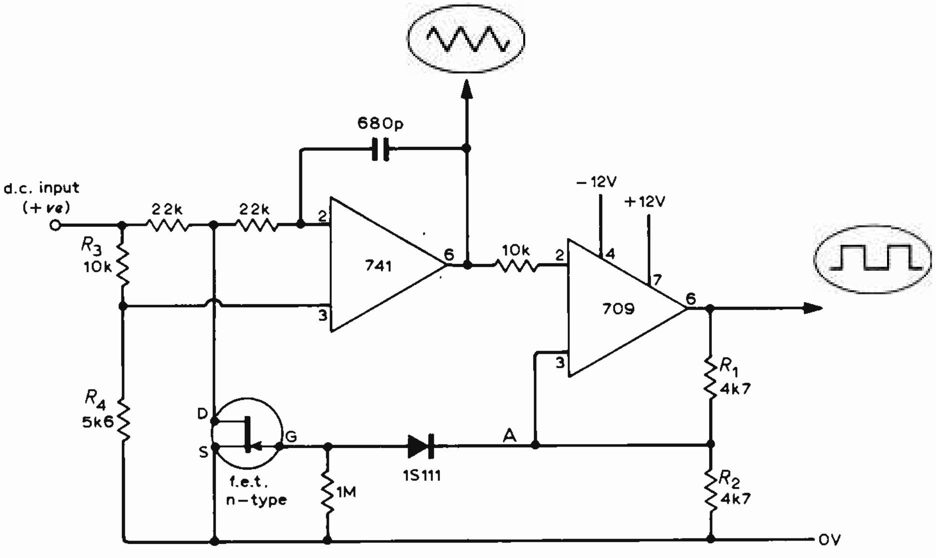
- Produce a frequency of 0-10kHz linearly related to a single control voltage, with a scaling of 1kHz per volt and zero frequency for zero volts control.
- Produce a good square wave and triangular wave suitable for sine shaping, i.e. constant amplitude.
- Circuit to be simple, reliable, self-starting with good temperature stability and zero warm-up time.

Mr. Price's circuit (Circuit Ideas, page 348 July issue) falls short of my specification in respect of the first requirement. Also, the frequency range of my circuit is much greater (0 to 10kHz compared with 100Hz to 3kHz), and Mr. Price's triangular waveform is not truly linear, but formed from a section of an "exponential" waveform. Other published circuits have also failed to meet this specification with the same degree of circuit simplicity as my own, e.g. Mr. Tidey's circuit (May, page 239) while giving the required outputs would require an additional amplifier to permit control by a single voltage, making the complete circuit a good deal more complex than shown in his diagram.

The circuit gives a good linear d.c.-to-frequency characteristic between 1Hz and 10kHz for up to 10V input, and works down to zero frequency. With a high-stability capacitor, the temperature coefficient is about 0.005% per deg. C between −40 and +100°C.

One of the advantages of the circuit is its flexibility: adjustment of the ratio of R_1 to R_2 gives triangular-wave amplitudes between 0 and 20V. The relative slopes may be adjusted with R_3 and R_4, and the bottom of the triangular wave can be clamped to almost any level by clamping the line A. Negative input voltages are easily dealt with by changing the f.e.t. type. With some modification, the unit can be made to operate over a wider frequency range, but normally some non-linearity occurs at very low input levels due to offset voltages, and at high frequencies due to the time taken for the 709 amplifier to come out of saturation. The d.c. source should be relatively low impedance or have a small capacitor across it to avoid problems due to the changing input impedance of the circuit as it switches. Also the second amplifier must have a very high slewing rate, hence the use of a 709 amplifier with no compensating components.

J. W. Howden,
Bristol.



Frequency doubler

Wide-band frequency doublers, which depend for their operation upon the low-level characteristic of germanium semiconductor diodes, can be designed using very few components. Representing diode currents as a power series it can be shown that for identical diodes in Fig. 1, $v_2=v_3$ and $v_1=\hat{v}_1 \sin wt$ then $v_4=A\,(1-\cos 2wt)$. A practical circuit is shown in Fig. 2. Adjust the low-frequency balance control for minimum distortion in the $2f$ output signal. At high frequencies capacitance trimming of the diodes and a wide-band differential amplifier are necessary. Circuit shown operates up to hundreds of kilohertz. Input signal amplitude is limited to about 60mV pk-pk.

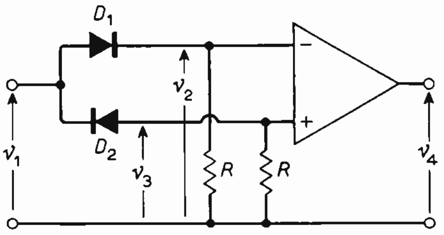


Fig. 1

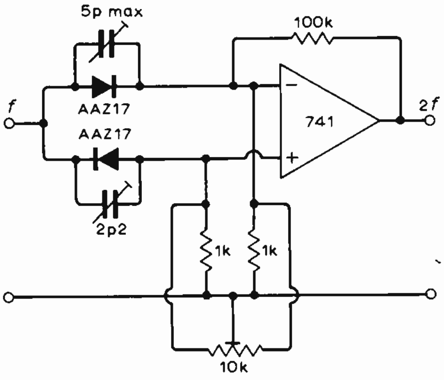


Fig. 2

R. E. Webb,
Queen Elizabeth College,
London.

Meter protection circuit

In C. Shenton's circuit in the October issue (page 475) the two diodes shown should be reversed. Low-leakage types should be used, e.g. OA202.

Metal-air Batteries

Developments in primary and secondary cells

Every two years since 1958 the Joint Services Electrical Power Sources Committee has sponsored a symposium in Brighton, devoted to research, design, development, production and use of electrical power sources (other than rotating machinery). The sponsoring committee includes representatives from the Ministry of Defence, Department of Trade and Industry, Government Communications Centre, Post Office, Atomic Energy Authority, N.R.D.C. and British Rail, and amongst other things, co-ordinates research and development on sources of electrical power in Government establishments, universities, and the industry. Of this year's record attendance — nearly 500 delegates — the majority were from abroad, with sizeable contingents from East Europe and Japan.

In our previous reports of these symposia, developments in well-known souces of electrical energy have been featured — lead-acid, alkaline (e.g. nickel-cadmium) and metal-halide secondary batteries, Leclanché and other primary sources, as well as fuel cells, solar cells and thermoelectric sources. Little was reported on the subject of metal-air cells, especially in rechargeable form, so this time we attempt to redress the balance.

Although the first zinc-air primary cell was demonstrated nearly a century ago, it is only recently that high-current-density air electrodes have become available as a result of fuel cell development. The cell can be thought of as derived from the Leclanché cell which it will be recalled, uses manganese dioxide as oxidizer at the cathode. It was in 1878, in fact, that L. Maîche replaced the manganese dioxide with pulverized catalyzed carbon to form the first air-depolarized cell. Zinc-air cells also resemble alkaline cells, which use potassium hydroxide as electrolyte, again with the mercuric oxice or manganese dioxide replaced by an air-breathing cathode.

Early air-depolarized cells could be discharged at high rates and had energy densities of over 200Wh/kg, but suffered from both low storage life and low active life due to water evaporation from the electrolyte. Life could be increased by adding water or electrolyte to the cells before, and during, use but there was still the disadvantage of the high cost of air electrodes, mainly due to the expense of the catalysts used. A mechanically rechargeable cell was consequently developed, recharged by replacing anodes and electrolyte, but costs were still relatively high and there were other problems with this system.

By the end of the 1960s cells were developed using low-cost catalysts in the air cathodes and the feasibility of making sealed cells had been demonstrated. And by 1972 sufficient progress had been made, especially in active life, to make commercial production feasible.

Thus the stage was set for the production of high energy and power density throw-away cells ideally suited to small motorized equipment (tape recorders, toys, shavers) and to communications equipment, pocket paging, and hearing aids. Applied to the portable transistor radio, the low internal resistance of the cell allows operation to a lower terminal voltage than with conventional cells.

Work on producing commercial cells is under way at Crompton Parkinson Ltd and at Energy Conversion Ltd. The Metair cells made by Energy Conversion are now in production in the R1 or N size. These have a capacity of 1.3Ah with a current rating of 150mA, at which rating energy density is 260Wh/kg. Discharge time at a current of 55mA is around 25h for comparison, the equivalent mercury-zinc cell would have a discharge time of around 6 hours. Production of further sizes is planned — R6 or AA size with a nominal capacity of 4Ah at 350mA, R14 or C size with a nominal capacity of 10Ah at 750mA and R20 or D size with a nominal capacity of 22Ah at 1.6A.

An important factor in zinc-air battery design is the need to ensure sufficient air access to the cathode areas. (A current of 100mA requires an air supply of 1.75cm^3/min.) In these cells therefore the cathode is outermost with the anode inside, in contrast to the common Leclanché cell arrangement. The air-breathing cathode is made from a catalyzed nickel mesh with an hydrophobic layer of p.t.f.e. around the outside. Apertures in the cathode allow hydrogen evolved due to self-discharge at the anode to pass. (This self-discharge is kept to a minimum by amalgamation of the zinc with 2% by weight of mercury.)

The zinc anode is made from compacting electrolytic zinc with a high surface area to form a hollow porous cylinder, the amount of zinc determining cell capacity. The anode is wrapped with separator/electrolyte (KOH) material, effectively insulating it from the cathode. A porous paper membrane, to distribute the air over the cathode surface, and an air reservoir lie between the cathode and plastics case. The advantage of this arrangement is that additional air can be provided to the cathode when high current pulses are demanded. The cell is protected by a plastics container and laminate film to minimize the diffusion of oxygen, water vapour and carbon dioxide into the cell, whose effects reduce storage life. Results of storage tests carried out at 20 and 40°C were 95 and 87% retained capacity respectively after 6 months storage. Active life – the time during which a useful discharge can be obtained after removing the cell from its container – has been dramatically increased for low-rate cells over the past two or three years, and at 0.6mA the cells would operate continuously for 12 weeks.

Metal-air secondary systems

The promise of the metal-air secondary system is electrical power at a competitive cost to, and at a higher energy density than, lead-acid batteries. A paper enticingly called 'A zinc-air battery for electric vehicle applications' turned out to be a negative report on the possibility of using the zinc-air system as a rechargeable battery. The target, based on experience with a lead-acid powered vehicle, was a peak battery power of 45kW (for a vehicle of 2,500Kg total weight and payload) to give a traffic compatibility comparable with a 950-kg payload petrol or diesel-engined delivery vehicle (i.e. an acceleration of between 20 and 35s to 70km/h) with a battery weight of 25% of total. This implied an energy density of 110Wh/kg and a peak power density of 75W/kg (65kWh and 45kW peak from a 600kg battery).

The problem in air electrodes in metal-air secondary systems is that they must be capable of cathodic conversion of oxygen in the air during discharge while allowing anodic evolution of oxygen during recharging.

The first disappointment in this paper came in getting the required aie electrode performance (a current density of 4kA/m^2 at 30kN/m^2 air pressure or 5kA/m^2 at 50kN/m^2) together with the required resistance to damage under anodic-cathodic cycling conditions. The author, D.S. Adams of Joseph Lucas Ltd, felt this to be incompatible with the prevention of shorting in the zinc electrode. During discharge zinc dissolves into the electrodlyte and is not deposited back on the electrode in the same shape it had before discharge. Zinc dendrites form leading to internal short-circuiting. Other ptoblems – water loss in the air and battery heating – as well as battery cost seem to put this one out of court. (Battery cost was estimated at £20 to £25 per kW of peak power plus £1 to £2 per kWh, 1970 prices.) These problems led to the conclusion that further investment in this source for this application was not justified.

Against this pessimism is to be balanced the optimism in a paper by S. Hattori and colleagues at Yuasa Battery Co., Japan. Their new cell design is claimed to avoid cell short-circuiting in zinc electrodes.

A third (nickel) electrode for charging is placed outside the air cathode and the discharge anode and on the anode side. During charge the electrolyte with zinc ions is circulated between cathode and adjacent electrode and the charge current flows from the third electrode. Almost all the zinc is deposited on the air-electrode side and even with charging at $4kAh/m^2$ short circuits have not occurred.

Oxygen evolved during charge does not come into contact with the air electrode, avoiding deterioration. As the additional electrode is not used during discharge and the electrolyte circulates along both sides of the zinc anode all the zinc is cleared away so the zinc deposit is similar every cycle. There are still problems to be investigated despite this hopeful possibility for cell construction, like additives to minimize the quantity of electrolyte required for charge and discharge, materials for the anode, and electrolyte circulation systems. An energy density of 80Wh/kg might be hoped for in a fully engineered battery but, to quote Dr Adams' reaction, they would be "very hard pressed" to reach this level with current elwectrode performance.

Air electrodes developed for fuel cells allow cathodic conversion of oxygen but anodic transfer and stresses due to oxygen bubble formation limit lifetime. Unfortunately the solution of introducing a third electrode between the metal and air electrodes, to act as counter-electrode to the metal electrode for oxygen evolution during charging, results in an increase in weight and volume which is not what is wanted in lightweight applications.

An air electrode capable of combining the anodic and cathodic function without its life being limited by corrosion is under investigation at Siemens in Germany for application to an iron-air cell. It consists basically of two layers, one a hydrophilic porous nickel sheet next to the electrolyte (KOH) and the other a hydrophobic carbon layer (with filler, binder and silver) next to the gas phase. The hydrophobic layer is similar to the single layer oxygen electrode used in fuel cells, also has an additional layer of sintered p.t.f.e. on the gas side. The hydrophilic layer forms a gas-stop layer during reduction, or discharge, and evolves oxygen during charge with the help of a catalyst. Although both materials must be resistant to corrosion, the materials on the gas side do not have to meet this requirement, which extends the range of materials to choose from. The gas-side layer is evidently protected from oxygen bubble stresses.

The most recent work reported at Brighton has achieved an increase in carbon activation by "gas treatment", eliminating the need for the additional silver catalyst. Unfortunately, the corrosion current increases dramatically for air and CO_2 treatment, and NH_3 treatment, which does not alter the corrosion current appreciably, only increases electrode potential by 50mV — still some way off the silver-coated potential. A limited coating of silver ($200g/m^2$) improves this by a further 50mV. Work has shown that current densities of $150A/m^2$ can be achieved — that needed for a peak output of 27.5kW (8.5kW continuous) estimated for a car of 1000kg and $2m/s^2$ acceleration — with an iron-air battery using small-area electrodes.

Tests are being made now with larger electrodes ($100cm^2$) making contact with the nickel layer rather than the carbon and using half as much silver (an economically "feasible" quantity), but so far poor connection between carbon and nickel layers has prevented meaningful results being obtained.

The widespread use of porous electrodes of course is to increase efficiency by increasing surface area, which can be thousands of times greater than the superficial area. A way of getting even greater surface area is to use a fluidized "bed" of small particles, by circulating electrolyte with a pump. Improved operating characteristics should be obtained as well because the diffusion rate of reaction products is increased with this fluid flow.

Particle agglomeration

A problem with such electrodes has turned out to be agglomeration of the particles during charging. Gillibrand, Gray and Gudger (Electric Power Storage Ltd) have developed an optical technique for observing this phenomenon and constructed an experimental perspex cell containing KOH and ZnO as electrolyte and a quantity of copper-coated glass particles $200m\mu$ in diameter. A fascinating film showed that a short time after applying a constant current, the particles became attached to the feed electrode and agglomerated; a little later zinc was seen to be deposited onto the particles. At higher fluid velocities, particles still stick together, though not to the feeder wire. Reversing the current separated the particles.

The zinc deposit was shown not to be responsible for this when the experiment was repeated without the ZnO in the electrolyte. Other electrolytes were tried, but this agglomeration occurred in both alkaline and acidic cases (but not in the case of a neutral solution of potassium sulphate). Spheres coated with a non-metal (carbon) showed no sign of this phenomenon at first, but when zincate was added to the electrolyte, agglomeration again occurred, suggesting that a metal-to-metal bond was responsible. No agglomeration was found with nickel or cobalt-coated particles.

The theory put forward for this is that of a very weak cold weld, formed at roughly the potentials at which the element would only be stable in the unoxidized state. Particles which were partially oxidized would weld together after a short delay, when presumably the oxide had been electrochemically reduced to metal. Two anomalies to this theory are the failure of nickel and cobalt to agglomerate — the authors suggest that the surfaces may not be completely oxide-free — and the absence of agglomeration with potassium sulphate.

It might be feasible to break up collections of spheres outside the cell, but sadly the investigation is not being continued.

The next three symposia will be held on 16-18 September 1974, 22-24 September 1976 and 26-28 September 1978 and the first of these, at least, will be in Brighton.

New Battery for Pacemakers

The life of primary batteries is inconveniently short for many applications — an acute embarrassment occurring in the particular case of implanted pacemakers, where there is the need to frequently replace the battery surgically.

In this situation perhaps the most appropriate energy source is a radio activated element, with a long half-life. Plutonium 238 having a half-life of 90 years is used in a new French design. This half-life means an almost constant (down to 92.6%) output for 10 years and it is estimated that about a third of pacemaker patients could use it. (This new source becomes cheaper than conventional electrochemical ones after about 5 years or 2 re-implants, the cost of implanting being three times that for pacemakers using ordinary sources.) The other advantage of this isotope is that it gives out only $\propto$ radiation in its pure state, which is absorbed by the capsule. Gamma or neutron radiation due to impurities like Pu236 or lighter elements, is reduced to a weak level by refining and by the cladding of several millimetres thickness. (Dose rate at the hotter points of the source is 2.5mrem* /h, being lowered by the surrounding tissue so that in a year the spinal cord receives less than 5 rem.)

Bismuth tellruide is the thermoelectric element, the number of thermocouples being chosen to give an on-load voltage of at least 0.5V (the minimum necessary to operate d.c. converters) at the end of 10 years. The generator, called Gipsie, is not designed to have the best possible efficiency: safety, reliability and ageing are the most important factors. In fact, with an output of 0.3mW and an input of about 90mW, efficiency is 0.3%.

* The rem (roentgen equivalent man) is a measure of biological effect, being the product of dose in rad and r.b.e., the relative biological efficiency.

Working Temperatures of High-power Loudspeaker Voice Coils

A simple technique for parameter measurement

by A. E. Falkus, B.Sc. (Eng.), F.I.E.E.*

The present demand for high output levels from electric guitars and sound reinforcement systems has focused attention on loudspeakers able to handle these increased powers. Since the efficiency of a cone-type, moving-coil loudspeaker normally does not exceed 10%, most of the input energy to such a speaker is lost as heat in the voice coil winding with a consequent rise in temperature. It is this rise in temperature which usually limits the power that a speaker can safely handle.

The simplest form of speaker voice coil consists of two layers of enamelled copper or aluminium wire wound on a cylindrical paper tube with a cellulose adhesive. The tubular former is cemented at one end to a conical paper or other form of diaphragm and the winding is located in a strong transverse magnetic field, so that when it is carrying alternating currents, axial forces are generated which cause alternating movements of the diaphragm and so create sound waves. As the current through the winding increases, its temperature rises and a point may be reached where the adhesive holding the turns in place softens or decomposes. The turns then slip off the former and the speaker is wrecked. If the low softening point adhesive is replaced by one capable of withstanding a higher temperature, then the power handling is increased. A point is reached, however, when the paper former becomes charred so that a better material than paper must be sought. Aluminium foil has been used for voice coil formers but, even when a gapped former is used, it introduces losses due to eddy currents which become progressively worse as the frequency rises. A material is required which has a high strength/weight ratio and is unaffected by temperatures up to 250°C.

Measuring the variables

To design a high-power speaker it is necessary to know the relation between input power and temperature rise for a given size of voice coil. Now, if the voice coil is removed from the speaker and tested on the bench by supporting it in free air and passing a known current through it, the voice coil is destroyed by a current much smaller than the maximum that it can successfully withstand in the speaker. This is because of the considerable cooling effect resulting from its movement in the speaker air gap. Static tests are thus of little help in determining the temperature rise under working conditions.

When a loudspeaker is in use a back electromotive force is generated in the voice coil due to its motion in the magnetic field in the same manner as in an electric motor. This e.m.f. opposes the applied voltage but is not usually exactly 180° out of phase with it. A loudspeaker connected in series with a 1Ω non-inductive resistor and fed from an audio oscillator will produce a voltage across the resistor in phase with the current flowing through the speaker. An oscilloscope can now be connected with its horizontal deflection across the speaker and the vertical deflection across the resistor. The figure on the tube will normally be a loop. When the frequency of the oscillator is increased this loop gradually becomes thinner until the main resonant frequency is reached when the trace becomes a straight line. If a capacitor is momentarily connected across the speaker at a frequency below the resonance the loop becomes thinner indicating that the current is lagging behind the voltage in this region.

As the frequency is increased above resonance the oscilloscope trace again becomes a loop but the addition of the capacitor now increases the width of the loop, indicating that the current is leading the voltage in this region. At a certain critical frequency, about six times the speaker resonance, the loop again becomes a straight line indicating that the current and voltage are again in phase. Above this frequency, the trace once more becomes a loop with the current lagging behind the voltage. At the critical frequency, where the current and voltage are in phase and the speaker offers a non-inductive load to the amplifier, it is found that the c.r.o. trace remains a line at all values of input power indicating that the generated back e.m.f. remains in phase with the applied e.m.f. for all current values. If at this critical frequency, a small current is passed through the speaker and the voltage across it measured, then this voltage will equal the arithmetical sum of the back e.m.f. and the voltage required to drive the current through the resistance of the coil, as measured on a d.c. resistance bridge.

At higher currents the back e.m.f. will increase due to large movements of the coil. The ohmic loss will also increase due not only to the extra currents but also to the rise in resistance of the wire as the voice coil heats up. It occurred to the author that this effect could be used to determine the rise in temperature of the coil on load. This critical frequency for a 12in high-power speaker is in the region 250 to 500Hz, where the movement of the speaker cone is small compared with the depth of the magnet gap. The movement of the voice coil, and thus the back e.m.f., will remain proportional to the input voltage at all values of input power in the working range. Thus, if the back e.m.f. is known for one value of the input voltage it may easily be calculated for any others.

All that is required to measure the relation between temperature rise and input power, at the critical frequency, is to connect the speaker in series with a 1Ω

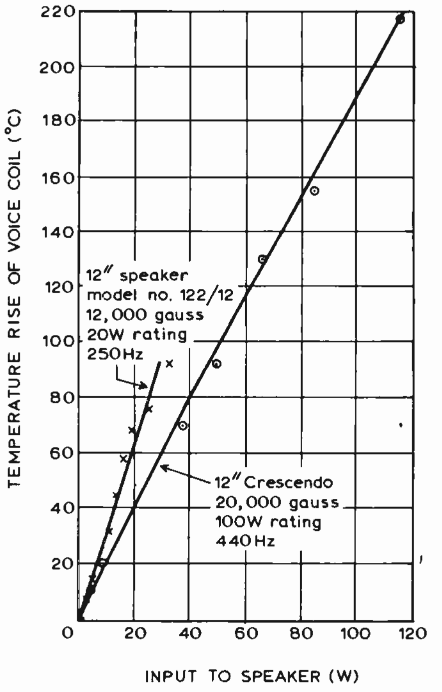


Fig. 1. The temperature rise of voice coils in high-power loudspeakers under working conditions.

non-inductive resistor and measure the voltages across this resistor and the speaker for various values of input.

The results for two 12in speaker units with different sizes of magnet are given in tables 1 and 2 and the graph in Fig. 1. The speakers were tested lying on their backs in free air. Voltages were measured with a high-impedance, multirange, solid-state voltmeter after allowing a couple of minutes to elapse at each current reading to allow the voice coil to reach its new temperature.

The voltage across the 1Ω resistor is equal to the value of the current in amps. Since amps and volts are in phase, the product of this current and the voltage across the speaker gives the watts input to the latter. If the d.c. resistance of the speaker is first measured, then, at a low current value insufficient to raise its temperature appreciably, the volts lost in the resistance of the voice coil may be taken to be the product of the d.c. resistance and this current. Subtracting this value from the voltage measured across the speaker gives the value of the back e.m.f. for this input while at higher input values the back e.m.f. rises in proportion. Subtracting the back e.m.f. from the speaker voltage at each input level gives the value of the volts lost in resistance at each input. Multiplying this by the current gives the resistance value in ohms and the % increase of resistance from cold can be calculated. Since the resistance of copper increases by 0.428% for each degree Centigrade rise in temperature, the % increase at each power level may be converted into temperature rise.

It is interesting to note that a higher flux density of magnet has the effect of reducing the temperature rise for a given input power. This is due partly to an increase in efficiency of the speaker, which implies a greater proportion of the input watts being converted into acoustic power and partly to improved cooling resulting from increased amplitude of motion of the coil. The ambient temperature at which these tests were made was 20°C, but when used in the normal way with the speaker enclosed in an air-tight box this could easily become 30°C. It therefore becomes clear that for a 12in speaker with 2in diameter pole piece to be rated at 100W, its voice coil must be capable of working satisfactorily at temperatures over 210°C. There is one small consolation for the loudspeaker manufacturer and this is that as the temperature of the speaker voice coil rises, its increased resistance tends to limit the power which an amplifier can supply, assuming this to have been matched to the speaker when cold.

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* Fane Acoustics

TABLE 1

12in "Crescendo" loudspeaker
nominal impedance 8Ω: main resonance 80Hz: d.c. resistance 7.3Ω: flux density 20,000 gauss: 2in diameter voice coil with two layers of 36 s.w.g. copper: critical and test frequency 440Hz: manufacturer's power rating 100W: back e.m.f. is 16.6% of input voltage.

(a) Current through 1 Ω resistor (A)	(b) Voltage across speaker (V)	(c) Input to speaker (W)	(d) Back e.m.f. (V)	(e) Volts lost in spkr. res. (b – d) (V)	(f) Resistance of voice coil (e ÷ a) (Ω)	(g) Increase in resistance from cold (%)	(h) Temperature rise (deg C)
0.20	1.75	0.35	0.29	1.46	7.3	0	0
0.56	5.05	2.83	0.84	4.21	7.52	3.0	7.0
0.98	9.30	9.12	1.54	7.76	7.92	8.5	19.8
1.40	15.0	21.0	2.49	12.51	8.94	22.4	52.3
1.80	20.5	36.9	3.41	17.09	9.50	30.1	70.3
2.00	24.5	49.0	4.07	20.43	10.22	40.1	93.7
2.20	30.0	66.0	4.98	25.02	11.37	55.8	130.3
2.40	35.0	84.0	5.81	29.19	12.16	66.7	155.8
2.60	44.0	114.5	7.30	36.70	14.12	93.5	218.3

TABLE 2

12in Fane No.122/12 loudspeaker
Nominal impedance 8Ω: main resonance 38Hz: d.c. resistance 7.0Ω: flux density 12,000 gauss: 2in diameter voice coil with two layers of 36 s.w.g. copper: critical and test frequency 250Hz: manufacturer's power rating 20W: back e.m.f. is 12.5% of input voltage.

(a) Current through 1 Ω resistor (A)	(b) Voltage across speaker (V)	(c) Input to speaker (W)	(d) Back e.m.f. (V)	(e) Volts lost in spkr. res. (b – d) (V)	(f) Resistance of voice coil (e ÷ a) (Ω)	(g) Increase in resistance from cold (%)	(h) Temperature rise (deg C)
0.20	1.60	0.32	0.20	1.4	7.0	0	0
0.43	3.50	1.51	0.44	3.06	7.11	1.8	4.2
0.81	6.85	5.55	0.86	5.99	7.40	5.6	13.1
1.10	10.0	11.0	1.25	8.75	7.96	13.6	31.8
1.20	11.5	13.9	1.44	10.06	8.38	19.7	46.0
1.30	13.0	16.9	1.62	11.38	8.75	25.0	58.4
1.35	14.0	18.9	1.75	12.25	9.07	29.7	69.3
1.55	16.5	25.6	2.06	14.44	9.31	32.9	76.8
1.70	19.0	32.3	2.37	16.63	9.79	39.5	92.3

Sixty years ago

Marconigraph November 1912. Under the heading "An After-dinner Autograph" appears an amusing anecdote recorded by one Signor Boriani, then co-proprietor of the Pall Mall Restaurant, Haymarket, London, who had many famous autographs in his album but had been unsuccessful in his attempts to obtain Guglielmo Marconi's. The story continues: One day he saw Mr. Marconi entering the restaurant, and noticing the table at which the great inventor intended to sit, he took the menu card, and for *Haricots verts au beurre,* which was an item on the bill of fare, substituted *Haricots verts à la Marconi,* in compliment to his guest. But the celebrated inventor was not to be bribed, however neatly a compliment might be turned. "Why should the beans be labelled '*à la Marconi*'", he remarked to his host, "seeing that they were — very ordinary beans?" Signor Boriani professed himself to be deeply hurt that his dish should be so lightly judged. "Quite ordinary beans?" he objected. "But did Mr. Marconi find them stringy?" "No, not the least suspicion of anything approaching a thread was to be found in them." Then Signor Boriani brought the whole battery of a Southerner's exquisite logic into play. "Therefore, they were in very truth *Les Haricots verts sans fils*" — that is to say, those French beans were acknowledged to be threadless — "but since Mr. Marconi was the inventor of La Télégraphie sans Fils, surely the beans had every right to be called *Haricots verts à la Marconi.*" There was no disputing such logic, and when the victor in the argument produced his little album what could Mr. Marconi do but sign the proffered page?

Corrections

"Pre-amplifier Using Op-amp Techniques." Readers have asked about the apparent inconsistency between Figs 3 and 8 in David Meyer's design in the July issue (pages 309-12). Although the collector of Tr_4 is returned to the -15V line in Fig. 3, Mr. Meyer tells us the circuit functions equally with the collector returned to the O-V line, as in Fig. 8. The Motorola transistors used have in-line pins, and are installed with their case flats as shown in Fig. 8. The centre (base) pin is pulled out of line in the direction indicated. The volume control potentiometer should have a value of 1kΩ, and not 10kΩ as shown.

In the article ***"Simple Amplifier for Muscle Voltages"*** by R.E. George, October issue, the formula for optimum source resistance which produces minimum transistor noise should be

$$\therefore R_S = 1/g_m \cdot \sqrt{I_c/I_b}$$

Professor P.B. Fellgett, author of the article ***"Directional Information in Reproduced Sound"*** in the September issue, has sent a revision for Table1, page 416. The relationship between any three outputs **X**, **Y** and **Z** should be

Separation X to Y and X to Z (dB)	Maximum separation Y to Z (dB)
3	
4.5	10.7
6.0	6.0
10	1.95
	0

World of Amateur Radio

Less TV interference

A recently issued analysis by the U.K. Ministry of Post & Telecommunications of the radio and television interference complaints investigated by the Post Office during 1971 records a useful 13% decrease in the total of 55,455 complaints compared with 1970. The number found to be due to amateur stations was 1027 compared with 1161 in 1970 and 1442 in 1969 — despite the growing number of licensed amateurs. When the complaints are classified into frequency bands, the figures underline the growing dependence of viewers on u.h.f. television (the 1970 figures are in parentheses): l.w./m.w. 38 (28); band I 467 (630); band II 44 (40); band III 300 (394); bands IV-V 173 (65); and mobile 5 (4). While the amateur clearly benefits from the growing use of u.h.f. television, the improvement is not as marked as might have been expected; this is almost certainly due to the unfortunate susceptibility of modern TV sets to strong local out-of-band signals. The recent extension of TV broadcasting hours in the U.K. means that there are now very few times of the day when amateur stations can be operated without risk of causing interference, and pointing to the urgent need for improved anti-interference measures to be adopted not only by amateurs but also by the television set-makers.

New look at v.h.f. receivers?

For many years, amateurs using the v.h.f. bands have concentrated on low-noise receiving systems. These often use high-gain, broad-band r.f. pre-amplifier, mixer and crystal-controlled oscillator chain as a converter in front of a multiple-conversion h.f. communications receiver. This is fine — so long as the number of very strong signals reaching the amplifier and mixer are few and well-spaced from the required signal. But the increased use of v.h.f., both by amateurs and professionals, means that there are now few locations where there are not at least some extremely strong signals to cause cross-modulation, intermodulation and spuriae. There is thus an increasing recognition that amateurs need to re-think their approach to v.h.f. reception to reduce these forms of interference by improving linearity and dynamic range — and also to reduce reciprocal mixing by improving the purity of the local oscillators.

These factors point to the use of such techniques as balanced f.e.t. or Schottky-diode mixers, low-gain r.f. stages with improved pre-mixer selectivity and preferably single-conversion techniques with its requirement for a tunable, stable oscillator having low-noise sidebands.

Such views were put forward by Arnold Mynett, G3HBW, shortly before he went to South Africa, although few practical designs to such specifications have yet appeared. A recent letter from George Elliott, VE2LI (former G5LI), underlines the need for such a re-think, with taxi-cab and police services operating in Canada immediately adjacent to the 144-MHz amateur band. He regrets that so many v.h.f. designs are still being published that ignore this urgent need to work well in the presence of extremely strong local signals.

On the bands

The amateur satellite Oscar 6 ("W.o.A.R." June 1972) carrying a 144/29 MHz linear translator may be in orbit by the time these notes appear. The launch is expected between October 12 and 16. The translator, 145.98MHz up and 29.5MHz down, could remain active for a year.

The system of phase-locked, infinitely clipped s.s.b. (see "W.o.A.R.", May 1972) has been used by the Dutch station PA0HVA in establishing a new Dutch 1296-MHz record of 570km. This mode is being used by an increasing number of Dutch amateurs on 144MHz to reduce the risk of audio breakthrough on TV sets without suffering the loss of communications effectiveness usually associated with narrow-band f.m.-type signals.

To mark 25 years of independence, Indian amateurs have permission to use the prefix VU25 instead of VU2 until December 31.

Louis Varney, G5RV, recently returned to the U.K. after operating for 18 months in Papua as VK9LV — altogether he has now operated amateur stations in 45 countries since obtaining his licence in the late 1920s.

Time of the Thursday transmission of the B.B.C. World Radio Club programme has changed from 1245 to 1330 G.M.T. Other times remain the same: Fridays 2345 (this goes out on m.f. as well as h.f.) and Sundays 0815.

The restriction of the 70 cm band to 430-440MHz with additional power and geographical restrictions on the segment 430 to 432 MHz) is expected to take effect from January 1, 1973.

The German beacon station DL0IGI, located 1200m above sea level near the Bavarian-Austrian border, is now operating on 28.195MHz, switching to 28.2MHz for five minutes at 15 and 45 minutes past each hour. Transmitter output is 100 watts to a vertical dipole and forms part of the special I.A.R.U. Region 1 project in conjunction with the GB3SX and 3B8MS beacons.

Xth British Commonwealth Games Award

To mark the Xth British Commonwealth games which are due to be held at Christchurch, New Zealand in January-February, 1974, all New Zealand amateurs are again being permitted to use the prefix ZM until February 2, 1974. A special British Commonwealth Award is being offered to mateurs working the following stations: one in Christchurch; one each with ZM1, ZM2, ZM3, ZM4 districts; plus one Commonwealth station in each of the three I.A.R.U. regions. A list of qualifying contacts, certified by two other amateurs, with four international reply coupons should be sent to Award Manager, PO Box 1733, Christchurch, New Zealand.

In brief

The Dutch amateur Win Dalmijn, PA0DD of Arnhem, who was elected as chairman of the executive committee of the I.A.R.U. Region 1 Bureau last May, died in September. . . . The British Amateur Television Club has published a short but most informative guide to slow scan television — SSTV was first developed by Capthorne Macdonald, WA2BCW about 15 years ago. The booklet covers principles, standards, monitors, flying spot scanners and cameras and provides a useful bibliography (available from A. M. Hughes, 93 Fleetside, West Molesey, Surrey KT8 ONQ, price 25p). . . . The R.S.G.B. has recently published the fourth edition of "Amateur Radio Techniques" The book now includes over 600 diagrams and an extended commentary on many aspects of the design and construction of amateur equipment and aerials (R.S.G.B., 35 Doughty Street, London WC1 2AE, price £1.80 including postage). The Alexander Volta radio-teleprinting contest will be held between 1400 to 2000 GMT on December 3 on all h.f. bands from 3.5 to 28 MHz. . . . The Italian station I1CAQ gained the third world r.t.t.y. championship award based on the results of six contests — no British amateur was in the top 50.

Pat Hawker, G3VA

New Products

Modular acoustic boxes

These units, manufactured and marketed under licence by Shone Sound Ltd, consist of wooden framed boxes 600mm square and 190.5mm deep surfaced with a specially perforated material and internally constructed on the lines of an egg crate.

Designed to act as sound absorbers rather than insulants, three models are produced: Type B for optimal absorption at 70 – 100Hz, Type WB covering the range 100Hz to 2.5kHz and Type W with an extended performance from 100Hz to above 8kHz. Typical maximum absorption coefficients of up to one are obtained.

These boxes are readily fixed to wall or ceiling surfaces enabling simple damping of room resonance and standing wave phenomena to be effected without major architectural or structural alterations. Shone Sound Ltd, 16 Bentley Way, Whitehall Road, Woodford Wells, Essex.

WW308 for further details

Electronic calculators

Four desk-top electronic calculators and a pocket unit have been introduced by Advance Electronics.

The pocket type, known as the Mini Executive (see accompanying photograph), is a floating-decimal-point, 8-digit, four-rule calculator (i.e., adds, subtracts, divides and multiplies). Answers may be optionally rounded-off to two decimal places. The Mini Executive operates from internal dry batteries and, using "long life" manganese-alkaline batteries, provides 15 hours' continuous operation. A kit of rechargeable cells is also available. Hand held calculators are often used at the owner's desk and a plinth has been designed to support the calculator in a convenient position on the desk top. This plinth incorporates a mains power unit to which the calculator may be connected and which bypasses the internal batteries when in use. Price including the optional charger/mains unit is £59.00.

Each of the four models in the Executive 16 range of desk-top calculators is a 16-digit, mains-operated unit and includes the following features: automatic constant, automatic clearing, repeat function (all four rules), simple reciprocals, automatic powers, 49-place exponent, left entry with overflow protection, two-key rollover, lock-out and automatic percentage calculation. The lowest priced Executive 16 costs £95.00. The Executive 16+1 (at £115) includes a special direct transfer accumulator (d.t.a.) memory for use as a side store, manual accumulator or sigma store. The Executive 16+2 (at £145) is similar but has two d.t.as and an optional sum-operand mode. Finally, the Executive 16R (at £175) provides a square root key in addition to all the features of the Executive 16+2. Advance Electronics Ltd, Raynham Road, Bishop's Stortford, Herts.

WW303 for further details (Mini Executive)
WW304 for further details (Executive 16 range)

Miniature power pack

Now available from Signatrol, the sole U.K. distributor for Analogic, is a power pack that gives dual output of ±15V from a +5V input, and is packaged in a physical size of 2 × 2× 0.4in depth.

The unit, MP.3015, is designed for digital systems where a logic rail of 5V is available but 15-0-15V is not, the converter gives a regulated output voltage at currents up to 200mA with an input impedance of only 0-10Ω. Digital systems frequently require ±15V power to work devices such as a-d converters, comparators, sample and hold amplifiers, operational amplifiers and other peripheral equipment. The MP.3015 provides enough power to supply ±15V for three a-d converters, and still have sufficient spare output to handle several operational amplifiers or comparators.

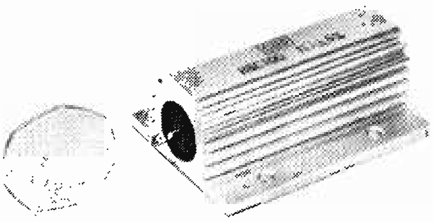
A further facility of the MP.3015 is that it provides the user with the option of either local or remote voltage sensing, depending upon the d.c. resistance of existing wiring and the degree of load regulation desired. The load regulation of the unit with local sensing is ±0.1% maximum and with remote sensing, load regulation will be improved to approximately 0.01%. Other pertinent parameters are: short-circuit protected, fast load transient recovery, and fully shielded. Signatrol Ltd., 6 Royal Crescent, Cheltenham, GL50 3DA.

WW306 for further details

100-watt resistor

New addition to the range of aluminium housed power wirewound resistors marketed by GDS Sales Ltd is a miniature 100-watt type.

Now measuring only 65 × 37 × 25.5mm, the redesigned resistor made by C.G.S. and designated type HSC100 can dissipate up to 100 watts at 20°C or 70 watts at 100°C, when mounted on a 315mm square, 3mm thick aluminium chassis. Free air rating is 30 watts at 20°C. These new HSC100 miniature power resistors are available (with 5% resistance tolerance) from 0.1Ω to 50kΩ. Temperature coefficient is 30 p.p.m./°C above 1kΩ, rising to 90 p.p.m./°C below 4.7Ω. Limiting element voltage is 1900 volts (r.m.s. or d.c.) with 5000V a.c. peak dielectric strength. Minimum dry insulation resistance is 10,000MΩ. GDS (Sales) Ltd., Michaelmas House, Salt Hill, Bath Road, Slough, Bucks.



WW305 for further details

U.H.F. aerials

Mazda have entered the u.h.f. aerial market with a range of lightweight, low-cost products suitable for all channels from 21 to 68.

Average gain figures for the standard models are 13dB and, for the high gain models, 15dB, with front-to-back ratios of 20dB and 22dB respectively.

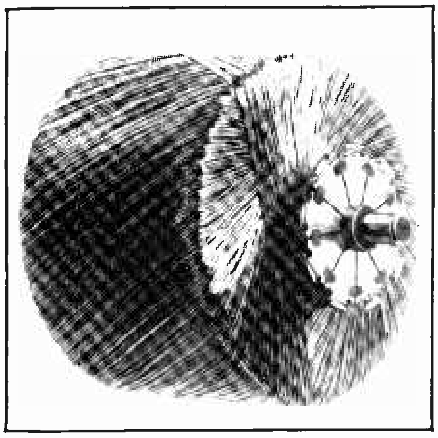
A total of six aerials make up the range, two each for group A and group B and a further two, each covering groups C and D. The recommended retail price is £3.00

for the standard and £3.75 for the high-gain versions. Mazda, Thorn Radio Valves & Tubes Ltd., Mollinson Avenue, Brimsdown, Enfield, Middx.

WW311 for further details

Low inertia d.c. motor

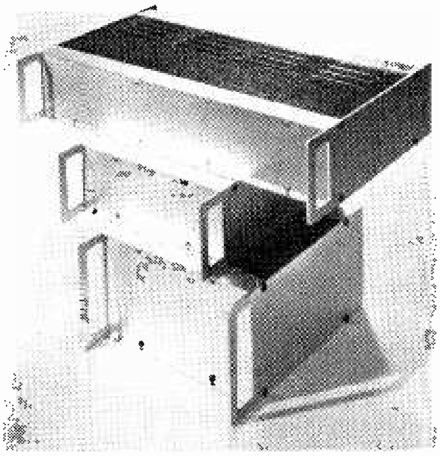
A new d.c. motor (type No. 9904 120 10801) has been added to the Impex Electrical range. Operating at 24V it has a speed of 2600 rev/min at 100g.cm torque. The rotor has a moment of inertia of only 38×10^{-3} g.cm^2 and a starting torque of 600g.cm. Sintered bronze bearings, a 9-segment commutator and silver plated 3-leaf brushes are designed for smooth running, long life and low noise level. Efficiency is claimed as better than 80%. Impex Electrical Ltd, Market Road, Richmond, Surrey.



WW302 for further details

Instrument cases

The Brightcase, one of the many West Hyde cases, is now being offered in a range of four sizes, providing two heights and two widths. These are 19in rack or half rack, either 3.5in or 5.25in high. The standard finish of anodized aluminium and black, and the integral design of combined side plates and handles, and black p.v.c. covered steel top and bottom panels is maintained. In addition these upper and lower panels are also available with louvres as an alternative when extra heat dissipation is required.



All the cases are delivered complete with front and rear panels and fully assembled. Brackets are available for rack mounting and internal chassis in quarter-, half- and full-rack sizes. Prices are from £6.80 each. West Hyde Developments Ltd, Ryefield Crescent, Northwood Hills, Northwood, Middx.

WW329 for further details

Differential amplifier

Extraction of the remote contribution from a telephone line pair, is a problem which has occupied the minds of broadcast engineers for some time. Until now the usual solution has been to use a hybrid transformer. The effectiveness of this method relies on a high degree of matching of line impedance. On average a 15dB rejection of the local contribution is possible with this system, but in general the equipment is cumbersome to use, requiring the matching and equalizing of each line before insertion into the broadcast material. A new solution was sought in which the rejection was independent of the line impedance which is always an unknown quantity.

Ludwig de Kesel, a young scientist at Hes Electronics in Brussels has studied this problem and the Hes TSV 30 differential amplifier is the commercial result of this work. With it the designer claims almost total independence of line impedance and a rejection of 30-35dB. The system uses a patented vector correction circuit, and includes a band-pass filter and a presence filter. The unit provides a complete interface between studio and telephone network.

In the U.K. the unit is marketed by Allotrope Ltd, 90 Wardour Street, London W1V 3LE.

WW317 for further details

Rotary attenuator

Precision and power handling are combined in a waveguide attenuator developed by Systron-Donner. This new device uses a longitudinal slot in a circular waveguide section which can be rotated to couple out varying amounts of microwave power. Insertion loss is 0.2dB maximum and typically less than 0.1dB from 8.2 to 12.4GHz. Change of attenuation versus frequency is essentially flat to 25dB and a maximum of 35dB attenuation is attainable.

There are two basic designs, an air-cooled unit dissipates 300W average at X-band and a water-cooled version which handles 5kW average. Peak power capacity without pressurization is approximately one-quarter of waveguide breakdown power. Input v.s.w.r. of the device is less than 1.15 and the phase shift as a function of attenuation is less than 3 deg.

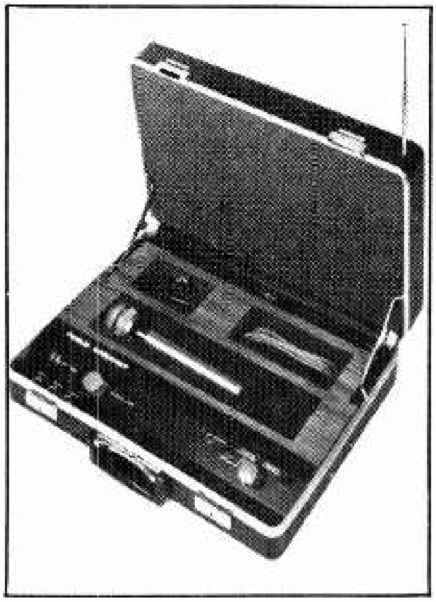
Attenuators are available in thirteen standard guide sizes from 1.7 to 40GHz and three types of controls are optional in either the air or liquid cooled versions. Attenuation values are graduated every 0.5dB to 5dB and at 1dB intervals thereafter to 20dB. A tape readout graduated every 0.01dB from 0 to 1dB, 0.05dB from 1 to 10dB and 0.1dB from 10 to 20dB also is available.

Rotary-slot attenuators are also available as electrically (servo) controlled units for remote operation. Systron-Donner Ltd, St. Mary's Road, Sydenham Industrial Estate, Leamington Spa, Warwickshire.

WW315 for further details

Radio microphone

The Reslo Cabaret is a complete radio microphone and receiver packaged in an executive styled briefcase. The ball top microphone, which is not much larger than a standard cable mike, houses the battery-operated transmitter which has an output of 10mW operating at 174.8MHz. The aerial is a free hanging wire of about 17in in length, allowing completely uninhibited movement. The receiver, which is mains operated, is contained in the briefcase which also houses a 17in telescopic aerial. This may be sited anywhere off stage and is simply plugged directly to the p.a. system. The microphone will operate up to a range of approximately 1,000 ft from the receiver, and the complete system weighs only 8 lb and is fully approved by the Post Office. Reslosound Ltd, Spring Gardens, London Road, Romford, Essex RM7 9LJ.



WW309 for further details

Broadband transistors

Two new products from Solidev Ltd for use in wired television distribution systems are the SC2000 series and the SC2600 series of n-p-n silicon high-frequency transistors for use in applications requiring low distortion and a low noise figure.

The SC2000 is in a TO-117 package with an integral heat sink stud, has a total power dissipation of 5W, a cross modulation distortion (x.m.) of −57dB at +50dBmV; an intermodulation distortion (i.m.) of −55dB at 50dBmV; a third harmonic distortion (t.b.) of −70dB at +50dBmV; and the derating above 25°C case temperature is 20mW/°C.

The SC2600 is in a TO-39 can and has a lower power dissipation of 3.5W, an x.m. of −50dB at +50dBmV, a t.b. of −75dB at +45dBmV, and the derating above 25°C case temperature is 28.6mW/°C.

Both devices have a low noise figure of 8dB at 200MHz; an f_T of 1.2GHz, a collector to base voltage of 40V d.c., a collector to emitter voltage of 25V d.c., a collector current of 0.4A d.c., and a storage temperature of −65 to +200°C. Solidev Ltd, Tubs Hill House, North Entrance, London Road, Sevenoaks, Kent.
WW328 for further details

U.H.F. cavity klystrons

A new range of television amplifier klystrons of the four integral-cavity type has been developed by ITT Components Group Europe. Coverage of frequency Bands IV and V, from 470MHz to 854MHz, is provided by the three new models, which can be used for peak synchronous power outputs of up to 12.5kW.

These klystrons (Z153/Z163/Z173) are said to offer considerable advantages over equivalent external-cavity types for which they are direct replacements. All tuning is done within the vacuum envelope thus eliminating periodic maintenance of the cavities, and the replacement of klystrons in their mounts is easier and quicker because of the integral construction.

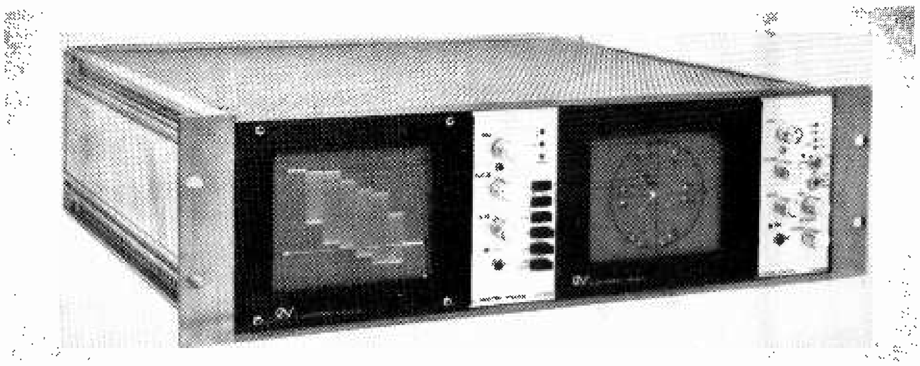
It is suggested that levels of radiation from the klystrons are reduced with integral-cavity units, thus improving the overall stability of the transmitter in which they are installed and good long-term stability is obtained. ITT Components Group Europe, Valve Product Division, Brixham Road, Paignton, Devon TQ4 7BE.
WW312 for further details

Mains isolator units

Designed for simple fitting to colour or monochrome TV sets with transistor audio outputs, R. W. Dixon & Company's mains isolator provides a safe, isolated output for TV hearing aids, extension loudspeakers and loop induction systems. Three models are available to match to any TV loudspeaker impedance. They also provide for an appropriate value of shunting resistor to be switched across the set output when its speaker is disconnected. R. W. Dixon & Co. Winton, Beacon Road, Crowborough, Sussex.
WW310 for further details

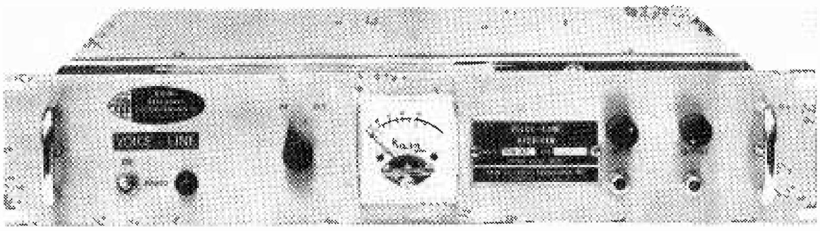
PAL vector monitor

Electronic Visuals Ltd, specialists in TV waveform measuring equipment, have introduced the EV4020 Vector Monitor which has been specifically designed for use with c.c.t.v., v.t.r. and educational television systems, in broadcast control consoles or any area where it is necessary to monitor colour subcarrier signals (PAL system). For ease of operation only three main control functions are provided — "phase align greater than 360°"; "gain select" for 100% and 75% amplitude of 100% saturated colour bars; "internal or external subcarrier reference and internal or external sync". A 10 × 8cm c.r.t. provides visual displays and the deflection factor is 0.7V for full scale 75% amplitude colour bars. The graticule is engraved with boxes for each colour bar, the inner boxes representing phase and amplitude error limits of ±3° and ±5% and the outer boxes ±10° and ±20%. For table top use the EV4020 is supplied in a bench case. Electronic Visuals Ltd, P.O. Box 16, Staines, Middx.
WW326 for further details



A.F. encoder for telephone lines

The Voice-line 67, from Kahn Research Laboratories, is designed to obtain improved quality speech over low-quality telephone or radio circuits. It is claimed that the quality and naturalness of speech is mainly limited by the loss of low-frequency components. The Voice-line equipment transmits the low-frequency sounds by notching a 300Hz slot in the voice spectrum at 2kHz and encoding the low-frequency sounds so that they may be transmitted in this narrow slot. At the receiving end of the circuit, the low frequencies are decoded and recombined so as to provide improved sound quality. The loss of the voice components around 2kHz is said to be undetectable even under severe listening tests. Because the low-frequency response is transmitted over a separate frequency band, noise components below 300Hz can be removed by the use of a high-pass filter, thus sharply reducing noise where only poor lines are available. The equipment, which may be battery or mains operated, comes in either a rack mounted version for studio use, or a portable model for outside broadcast use equipped with amplifiers and faders for up to three microphone inputs. Interface International, 29 Market Street, Crewkerne, Somerset.
WW307 for further details



Data communications systems

General Telephone & Electronics has announced a compact, easy-to-operate data communications system which transmits up to 25 data signals simultaneously over a single private telephone circuit.

The new system, called the 25C, operates in the low-speed data transmission range which enables the user to satisfy numerous data requirements with a single voice-frequency circuit.

The variations available range from transmission of a single channel at a speed of 600 bits per second to transmission of 25 channels at 75 bits per second. In the 25-channel application, the equivalent of 2,500 words a minute can be transmitted over a single voice circuit. GTE International Systems, 21 rue du Rhône, 1204 Geneva, Switzerland.
WW313 for further details

Ferrite erase heads

Two new magnetic tape heads have been added to the range manufactured by Phi Magnetronics Ltd, of Falmouth, Cornwall. One type, AAE/10F, is a full-track erase head for use on $\frac{1}{4}$-in tape transport mechanisms. The other, an addition to their compact cassette tape head family, is a 2/2 ferrite erase head type CCE/8F. Data sheets for both types are available. Phi Magnetronics Ltd, Penwerris Lane, Falmouth, Cornwall.

WW 319 for further details

Log picoammeter

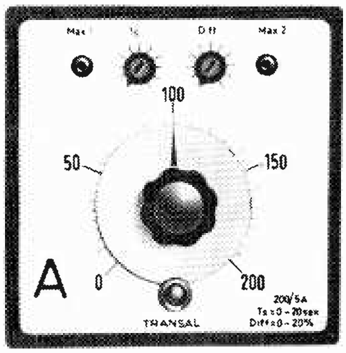
Keithley Instruments, of Reading, have announced a new logarithmic picoammeter, model 26000. Three basic units are available. Model 26100 measuring from 10^{-3} to 10^{-11} amperes, 26200 from 10^{-4} to 10^{-12} amperes, and 26300 from 10^{-7} to 10^{-13} amperes in one range. A switch is incorporated allowing quick recovery of large overloads. Since chassis ground and input low are connected via a shorting link, the system designer may select the point of grounding anywhere in his system. A wide variety of standard options are available. They include either negative or positive inputs, and dual polarity input. The selected current spans up to 8 decade and output voltage up to 10V. Keithley Instruments Ltd, 1 Boulton Road, Reading, Berks.

WW316 for further details

Control units

Supplementing their range of indicating and regulating equipment, Rayleigh Instruments Ltd has introduced a new range of solid-state instruments designated "Transal" for control of temperature, current, voltage, watts and volt-amp products, frequency, r.p.m. etc; in fact any variable which can be expressed in the form of an electrical d.c. or a.c. signal.

These controllers can be fitted with one or two electrical contacts and other features such as time delay, proportional regulation, hold-on circuits and step control action. They operate on an auxiliary power supply of 110, 220 or 240V a.c. and power consumption is limited to 6VA. Rayleigh Instruments Ltd, 271 Kiln Road, Benfleet, Essex.



WW321 for further details

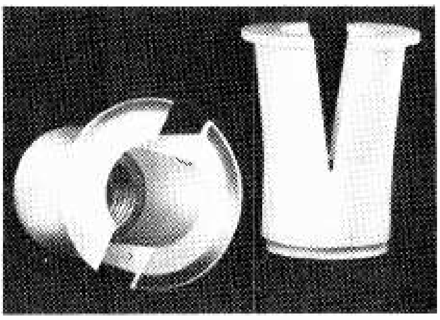
Digital display

From FR Electronics (Opto-Electronics Group) a new gallium phosphide light emitting diode digital display, type SLA-1, offering a character height of 0.33in within a standard 14-pin dual-in-line package. The SLA-1 utilizes the multi-directional light output of gallium phosphide chips to provide a bright, easily read display. Price in 100 off quantities is £3.34 each. FR Electronics, Opto-Electronics Group, Wimborne, Dorset.

WW325 for further details

Blind caged nuts

Spirol Industries Ltd, announce a new range of blind caged nuts designed to provide an economic and reliable method of assembling components to sheet metal, plastic sheets and thin wall plastic mouldings. The patented fastener consists of an internally threaded knurled brass nut within a nylon cage. The method of fixing is fast and simple. Working from one side of the assembly, the fastener may be pressed by hand into a drilled or punched round hole. Because the outside diameter of the split nylon cage is larger than the diameter of the hole the radial tension after insertion holds the fastener securely in place before assembly. On insertion of the screw, the knurled nut is drawn up the nylon sleeve forming a substantial bulge, which seats itself firmly and positively against the component material.



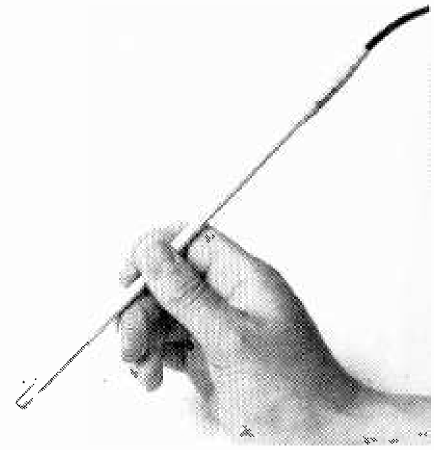
If required, the fasteners may be removed and replaced any number of times without damage either to themselves or to the workpiece. Available in four standard sizes each with internal thread forms. Spirol Industries Ltd, Browells Lane, Feltham, Middx. TW13 7DX.

WW327 for further details

Gaussmeter probes

The latest series of gaussmeter probes from F. W. Bell Inc. are solid state, magnetic field sensors in rugged packages, and are claimed to give accurate, repeatable and stable field measurements.

Models are available for transverse, axial, two axes, or three axes field measurements with a variety of field ranges, field sensitivities and physical configurations for each.



Calibrated extension cables and high sensitivity magnaprobes are also available and individual probe linearity curves are offered as an option. Euro Electronic Instruments Ltd, Shirley House, 27 Camden Road, London N.W.1.

WW 320 for further details

D/A converter

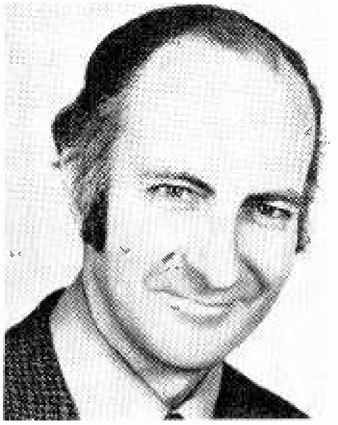
A high-speed moderate resolution d.a. converter has been announced by Tranchant (UK) Ltd which contains within a single package all elements including input buffer logic, electronic switches, ladder network, and a precision voltage reference source. Main feature of the DAC-GI series, manufactured by Datel Systems Inc., is the output settling time of 25ns to within ±1% of the final value, allowing for an update word rate of 50MHz. Full scale output is ±2.5mA with a maximum voltage compliance of ± 1.2V. Output linearity is ± 2.5μA with a current resolution of 5μA. Input digital word length is ten binary bits and input digital coding is straight binary for unipolar output and twos complement for bipolar output. All inputs are compatible with standard t.t.l./d.t.l. logic levels. Stability is better than ±0.05% for six months. Tranchant (UK) Ltd, Tranchant House, 100a High Street, Hampton, Middx.

WW322 for further details.

About People

Ken Bearcroft was recently appointed product marketing manager of the Industrial Controls Division of Advance Electronics Ltd. He joins Advance after spending some three years with Marconi Instruments in the U.S.A. as manager of programmable systems. From 1955 to 1969 Mr. Bearcroft, who previously spent some years at the Royal Radar Establishment, Malvern, on radar research, was involved in the design and development of automatic test equipment at Hawker Siddeley Dynamics.

Jermyn Manufacturing have appointed **John Long** as senior R & D engineer to take charge of their enlarged research laboratory at Sevenoaks. Mr. Long was previously senior process engineer with Plessey Radar, where he was responsible mainly for printed circuit manufacture and assembly techniques. Before that he was a materials engineer with Vatric Control Equipment.

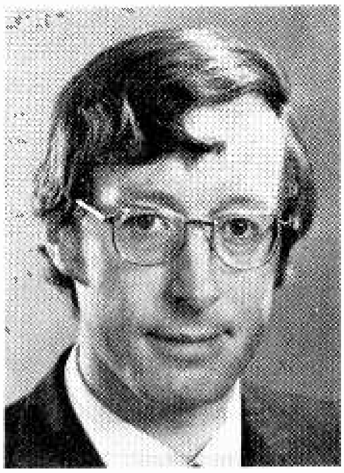


John Long

Marc Broussine, 47, a French National, born in Toulouse and educated at Sorbonne University, Paris, has joined the Export Sales Division of Ultra Electronic Components Ltd. He has a B.Sc. in electrical engineering, an M.Sc. in physics and since graduating has specialized in semiconductor applications and manufacture. Mr. Broussine was at one time head of the applications department of Plessey (Semiconductors) Ltd, Swindon, and earlier technical manager of MCP Electronics.

Orlando Oldham, a director and deputy chief executive of the Royal Worcester Group, has been appointed chairman of Welwyn Electric Ltd. **R. H. W. Burkett,** O.B.E., is resigning as managing director of Welwyn but will serve the company in a non-executive capacity as deputy chairman and consultant director. He will be succeeded as managing director by **J. E. Herrin,** M.I.E.E., who is joining the company from Federal Pacific Electric Co, of Newark, New Jersey. Mr. Herrin, who is 42, served in the Royal Navy as a Lieutenant from 1953 to 1955. He was then employed by A. E. I. in various capacities, eventually as manager of the Control Applications Department in Rugby. He went to America in 1967. Welwyn have also announced the retirement of **C. W. Martin,** director of production services, after more than 28 years service.

John Scott, aged 35, has joined Computer Data Processing Ltd (formed to integrate the computing activities of IPC Business Press) as sales manager. Mr. Scott joins the company from International Computers Ltd, where he was a programmer and systems analyst for nine years, prior to his transfer to sales.



John Scott

H. H. Deters has been appointed manager of Siemens' Congleton manufacturing and service division. He is responsible for the manufacture and assembly of equipment in their new factory and also for after-sales service. Mr. Deters joined Siemens AG in their Bremen works in 1959. Three years ago he came to Siemens in London to take over the Service Department. Siemens have also announced the appointment of **W. Gruber** as manager of the semiconductor division. He will be responsible for marketing and sales. He gained his technical experience in the semiconductor export sales group with Siemens in Munich, where he spent five years.

Charles Wofford, B.Sc., previously Texas Instruments' manager of discrete products and all manufacturing activities, has been put in charge of TI's Northern Europe Semiconductor Components Division centred at Bedford. A graduate of the University of Texas, El Paso, he has been working for Texas Instruments for 14 years. Prior to joining Texas Instruments Ltd, Bedford, in 1970, he was for four years the manufacturing manager at the Sherman, Texas, plant. For eight years before that he was involved with the manufacturing operation at the parent company's main plant in Dallas, Texas.

Charles Wofford

John Fletcher has joined M. B. Metals Ltd, of Portslade, Sussex, as general sales manager and will be responsible for sales of the company's products in computer and data logging systems and film wire applications. He was previously with the Dowty Group.

R. A. Cole, who is 36, has been appointed sales manager of the Valve Product Division of ITT Components Group Europe. He was formerly sales director of Fleet Electronics and general manager of Logic Applications. Mr. Cole was with ITT from 1966 to 1970 as a product sales engineer for valve products, prior to which he was with M-O Valve and Mullard.

Two research students have each received an I. E. E. – Hudswell Award. **Norman Cook,** of the Electrical Engineering Department, King's College, London, will use his award of £100 to purchase equipment to assist investigations aimed at improving the understanding of the basic cathode-emission mechanisms in gaseous discharges. **Frederick Perkins,** of the University of Dundee, is to use his £100, to help with his research in the field of medical engineering in connection with the developnent of true predictive monitoring of the electrocardiogram of patients suffering from heart disorders. The Hudswell Award, instituted in 1968 under the will of P. S. Hudswell, is intended to assist in the support of research in the fields of electrical and electronic science and engineering being carried out by members of the Institution. The award is made only to research students in universities and colleges within the United Kingdom. Particulars of the conditions governing the award and application forms for the 1973 award have to be obtained from the Education and Training Officer at the I. E. E., Savoy Place, London WC2R 0BL.

OBITUARIES

J. H. Cotton, M.B.E., for 26 years executive director of the Dubilier Condenser Company, of which he was managing director from 1966 to 1971, died on September 2nd. He was 64. Mr. Cotton worked for Cornell Dubilier in the United States for some years before he came to England in the early 1930s to join the British company. When he left Dubilier in 1971 he formed VTM (UK) Ltd in association with Vitrohm of Copenhagen.

E. A. Carter, who died recently aged 65, was for some years manager of Bush Radio's factory in Plymouth. His career in the radio industry began at the Philips works at Mitcham, and in the 1930s he was with Cossor at Highbury, where he was concerned with the company's production of radar equipment. After a short while with Rees-Mace Ltd, Mr Carter joined Bush in 1948 and continued with the Rank Bush Murphy company after the 1962 merger. He left R. B. M. in 1965 to become a director of W. G. Heath Ltd, west country electrical and radio contractors.

Literature Received

For further information on any item include the WW number on the reader reply card

ACTIVE DEVICES

Arrow Electronics Ltd, 7 Coptfold Road, Brentwood, Essex, have sent us the mail order electronic components catalogue for 1972 ....WW400

The General Electric semiconductor data handbook includes information on solid state lamps and circuit assemblies. Celdis Ltd, Head Office, 37/39 Loverock Road, Reading, Berks, RG3 1ED ....Price £2

The model 4290 analogue divider, described in a data sheet, has an accuracy of 0.5%, accuracy drift 0.01% per °C and a temperature range of $-25°$ to $+85°$C. Burr Brown International Ltd, 25 King Street, Watford WD1 8BY WW401

Dewtron modules for music synthesizer construction — including oscillators, power supplies and sample and hold units — are briefly specified and priced in a series of leaflets. Design Engineering (Wokingham) Ltd, 254 Ringwood Road, Ferndown, Dorset BH22 9AR WW402

Quarndon Electronics (Semiconductors) Ltd, Slack Lane, Derby, have sent us four publications:

- Texas Instruments 74 series t.t.l. (product specifications) WW403
- Signetic linear and m.o.s. devices (product specifications) WW404
- SGS i.c. catalogue WW405
- Op-amp parameter comparison wall chart WW406

Transistors, diodes, resistors, switches and motors, with prices, are included in a stock list published by Greenweld Electronics, 24 Goodhart Way, West Wickham, Kent, BR4 OES WW407

Electrovalue Ltd, 28 St. Judes Road, Englefield Green, Egham, Surrey, have sent us catalogue No. 6 including information on semiconductors and i.cs, equivalents tables and outline diagrams WW408

PASSIVE DEVICES

Specifications of a production range of passive and electro-mechanical devices are covered in the product catalogue of Waycom Ltd, Wokingham Road, Bracknell, Berkshire RG12 1ND WW409

Revised data sheets on microspot c.r.ts, solid-state light sources, industrial valves and electronic display equipment (data distribution No. 11) have been sent to us by Ferranti Ltd, Gem Mill, Chadderton, Oldham, Lancs. WW410

A female connector, known as the "Quickie" is described in a product sheet. The connector terminates multi-lead flat cable without stripping. Berg Electronics NV, 's-hertogenbosch, Helftheuvelweg 1, P.O. Box 2060, Holland WW411

We have received a news bulletin (no. 2, vol. 4) from A. F. Bulgin & Co. Ltd, Bye-Pass Road, Barking, Essex, which lists plug, socket and switch products and describes a humidity test chamber WW412

Products included in the Lucas 1972-73 abridged catalogue, are semiconductor and optoelectronic devices, manufactured by Joseph Lucas (Electrical) Ltd, Mere Green Road, Four Oaks, Sutton Coldfield, Warwicks WW413

EQUIPMENT

A new catalogue of h.f., s.s.b. radio equipment contains information on transceivers, transmitters, receivers and auxiliary equipment. RF Communications Inc., 1680 University Avenue, Rochester, N.Y. 14610, U.S.A. WW414

The series T6000 "explosion-proof" tachometer, the subject of a product leaflet, provides a measurement of r.p.m. or linear speed. Dynalco Corporation, 4107 N.E. 6th Avenue, Ft. Lauderdale, Florida 33308, U.S.A. WW415

Techmation Ltd, 58 Edgware Way, Edgware, Middlesex HA8 8JP, have sent us equipment data sheets including the following subjects:

- 11A photometer/radiometer WW416
- 21A optical power meter WW417

The Servo model 404 multi-band sweeper (1-18GHz), described in a leaflet we have received, has a built-in programmer which sweeps all bands omitting those frequency ranges not required. Tony Chapman Electronics, 3 Cecil Court, London Road, Enfield, Middlesex. WW418

Avel-Lindberg Ltd, 13/16 Ayron Road, South Ockendon, Essex RM15 5TD, have issued a data sheet and price list on their MP4 range of 500VA solid-state static inverters WW419

Price lists and details of medium-power lasers are contained in a folio sent to us by Spectra-Physics Ltd, 5 Wolsey Road, Hemel Hempstead, Herts WW420

"Tekscope", vol. 4 no. 3, contains a description of the 7704A 250MHz bandwidth, modular oscilloscope system. Tektronix U.K. Ltd, Beaverton House, Harpenden, Herts WW421

Video and audio monitors for use in c.c.t.v. systems are the subject of a series of product leaflets. Decca Radio and Television, Ingate Place, Queenstown Road, London S.W.8 ....WW422

Specifications of a Datalab 256 channel, low level, analogue multiplexer are given in a data sheet sent by Data Laboratories Ltd, 28 Wates Way, Mitcham, Surrey, CR4 4HR WW423

Two audio products described in leaflets sent to us by Nottingham Audio Services, 13 & 15 Foxhall Road, Forest Fields, Nottingham NG7 6NA, are:

- M70 mixer/pre-amplifier (three channels, o/p variable from 0 to 775mV) WW424
- 70 + 70 stereo power amplifier (70W per channel, r.m.s. continuous sine wave into 8 Ω) WW425

We have received information on the operation of a range of electronic switches (types 5A, 5B, 6A, 6B) which are dependent on conducting liquids, which enable latching circuits to be triggered where required. The Albatross Electronics Co., P.O. Box 28, Camberley, Surrey WW426

Product leaflets sent to us by Marconi Communication Systems Ltd, Broadcasting Division, Chelmsford, Essex CM1 1PL, include:

- B7320: 10kW u.h.f. TV transmitter WW427
- B7317: u.h.f., i.f. drive transmitter WW428
- B3215: mark VIII automatic colour TV camera WW429

Prices and details of standard equipment for (a) TV signal coding and colour caption synthesizing and (b) vision mixing and special effects are listed in a leaflet for September 1972. Michael Cox Electronics Ltd, 67a Holly Road, Twickenham, Middlesex TW1 4HF WW430

The "AC" series of solid-state timers for switching a.c. power is specified in a leaflet. Models in the range have overlapping ranges from 0.1-5s and 6-300s with ratings up to 1A. Tempatron Ltd, 5 Loverock Road, Reading, Berks. WW431

A video display, the VT109, is described in a leaflet we have received. Three standard models are available: (1) colour with alphanumerics and graphics, (2) monochrome with alphanumerics and graphics, (3) monochrome with alphanumerics. Moore Reed and Co. Ltd, Walworth Industrial Estate, Andover, Hampshire WW432

Eagle International, Heather Park Drive, Wembley, HA1 1SU, have sent us their latest brochure containing brief specifications for over 60 of their audio products. WW437

A catalogue giving specifications and prices for electrical measuring instruments, also includes power supplies, cells and bench aids. Electroplan Ltd, P.O. Box 19, Orchard Road, Royston, Herts SG8 5HH WW438

APPLICATIONS

Switching and mixing equipment for video systems is the subject of a booklet received from Prowest Electronics Ltd, Airfield Estate, White Waltham, Maidenhead, Berkshire WW433

GENERAL INFORMATION

A third edition of the handbook "Noise Measurement Techniques" has been published by Dawe Instruments Ltd, Concord Road, Western Avenue, London W3 OSD, who manufacture sound level measuring equipment WW434

Short courses in electrical engineering and physics are listed in a leaflet from the Hatfield Polytechnic, Hatfield, Hertfordshire.

A booklet describing the courses for 1973 planned by the Harwell Education Centre A.E.R.E. Harwell, Didcot, Berks., is in two parts: (1) courses for participants outside the Atomic Energy Authority, (2) courses arranged for authority staff. Course fees are also included.

We have received the 1972/73 prospectus for the Department of Electrical and Electronic Engineering, Plymouth Polytechnic, Drake Circus, Plymouth, PL4 8AA.

The "Aviation Product Guide 1972/73" lists products and their manufacturers who are members of the Electronic Engineering Association, Leicester House, 8 Leicester Street, London WC2H 7BN WW436

"Outlook for optics in information processing" is a research report on world markets for optical systems. Sira Institute, Chislehurst, Kent................Price £24

Loudspeaker Enclosure Survey

by Stanley Kelly

The purpose of a loudspeaker system is to provide a sound field which is, within practical limits, an exact replica of the original sound. This ideal is, in practice, considerably modified not only by the characteristics of the loudspeaker, but also by the acoustics of the room in which it is operating. There is general agreement on the optimum reverberation time of a room for best music listening conditions (the values are somewhat longer than for speech). Fig. 1 shows these values for frequencies above about 500 Hz. The relative reverberation time increases at lower frequencies, rising to about ×2 for 50 Hz. Thus, for an average domestic living room, about 2000 cu.ft, the optimum reverberation time is about one second and, in point of fact, most domestic rooms do approximate this value.

The trend in the theory of room acoustics is towards considering the source of sound, the room, and the receiver or "sink" all as part of a unified dynamic system. This premise is required to bring out the inter-reaction between the source, sink, and room, and their effects on the steady state and transient aspects of sound transmissions in the room. In this theory, the room is considered as an assemblage of resonators and the walls of the room as terminal impedances determining absorption and reflection. A rectangular room has a probable infinity of resonant frequencies. If the wall impedances are pure resistances these frequencies are given by

$$f = 1740 \left[\left(\frac{n_x}{l_x}\right)^2 + \left(\frac{n_y}{l_y}\right)^2 + \left(\frac{n_z}{l_y}\right)^2 \right]^{1/2} \quad \cdots\cdots (1)$$

where $n_x, n_y, n_z = 0, 1, 2 \ldots\ldots\ldots$ and l_x, l_y, l_z = dimensions of the rectangular room in centimetres. The distribution of these "allowed" frequencies (at which resonance occurs) may be described by a three-dimensional plot in "frequency space"; each vector to a lattice point is associated with a natural frequency or normal mode of the room. The shortest vector corresponding to the lowest frequency is determined by the longest dimension of the room. The direction of the vector from the origin to a lattice point indicates the direction of excitation of that frequency in the room and the length of the vector is proportional to its frequency. At low frequencies, there may be an appreciable frequency interval between the natural frequencies if the room is small; at high frequencies the number of natural frequencies for a given frequency interval is proportional to the square of frequency.

Reverberation

Using this concept of multiple natural frequencies the decay of sound in a room may be described as follows: assume that acoustic energy is being supplied to a room and that steady state conditions occur, i.e., the absorption at the boundary is equal to the rate of supply, the resultant standing wave systems depends not only on the room and the frequency but also on the location and orientation of the source. When the source of energy is stopped, each individual mode of vibration of the room will decay exponentially, and the combined effect of these is called reverberation. Only the modes having "allowed" frequencies near the frequency of the steady state excitation will contain appreciable energy. By definition, reverberation time is the time required for mean energy density in the room to drop by 60dB. While this mean may be the result of a large number of rates of decay, each of which is individually exponential, the combined value in general is not given by a single exponential term. This accounts for the fact that the slopes of the mean-energy-density-time-decay curves for the average room are not uniform. If the absorption is moderate, the approximate reverberation time in seconds is given by

$$T = 0.00161 V/a \quad \ldots\ldots (2)$$

where V = the room volume in cu. cm and a = total room absorption.

Corresponding to this type of energy decay in the room there is a growth curve. When a source suddenly emits energy into the room each of the excited modes absorbs energy in an exponential manner until a steady state value is reached (theoretically, after an infinite interval of time). The intensity *(I)* of the sound wave is a measure of the energy/sq. cm/sec., and the energy absorbed by the boundaries of the room/sq cm/sec. is therefore *Ia* watts. The total power absorbed in the room will therefore be *Ia* watts where *a* is defined in the equation above, or mathematically,

$$W_a = Ia \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where I = sound intensity in watts/sq.cm

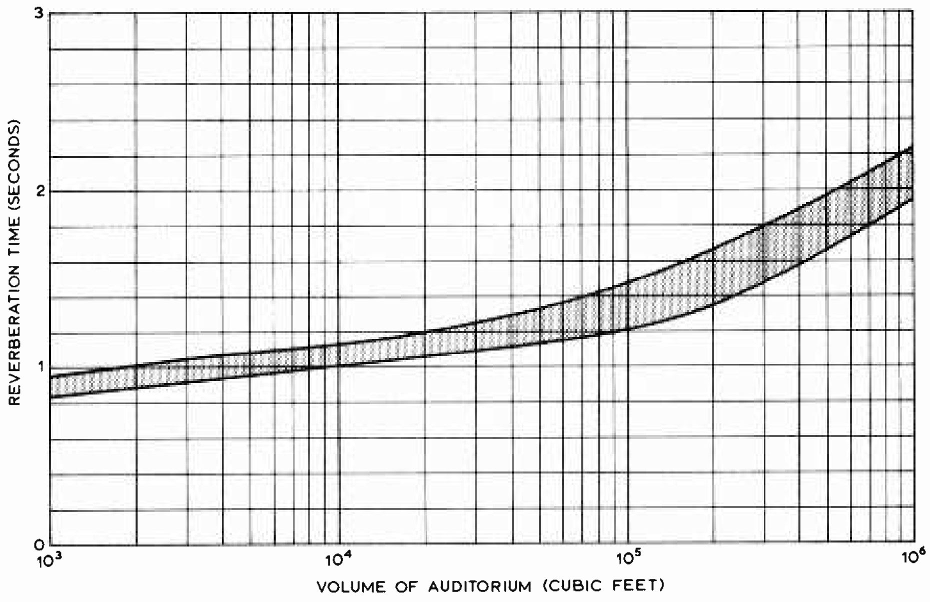


Fig. 1. Optimum reverberation time for listening rooms at 500Hz.

and W_a = acoustic power radiated by the source.

The acoustic power equals the product of the speaker efficiency and the electrical signal input power. If the room absorption is known, the speaker efficiency in this room may be determined by measuring the average sound intensity of the room. By combining equations (2) and (3) above we get:—

$$I = 620\ W_aT/V \text{ watts/sq. cm} \quad (4)$$

Room power requirements

If we know the desired sound intensity, the acoustic power W_a required to produce it may be obtained from equation (3) by knowing the total room absorption, or from equation (4) by knowing the room volume and reverberation time. Reverberation time is the easiest to measure and Fig. 2 shows the relation between the volume of the auditorium, reverberation time, and the sound power in acoustic watts required to maintain the uniform pressure of +30dB relative to 1 microbar (+104dB relative to 0.0002 microbar.) There is considerable difference of opinion on what constitutes acceptable levels of reproduced sound. The sound pressure level of normal speech at a distance of 6in is about +74dB; +94dB is "loud" music (about the maximum on average domestic reproducing equipment); +104dB is very loud (about the maximum volume from the Albert Hall organ at 30ft); and approaching the threshold of pain maximum levels of +114dB to +120dB are obtained from reinforced "pop" music in dance halls, discotheques, etc.

Loudspeakers

A loudspeaker is a device which is actuated by electrical signal energy and radiates acoustic energy into a room or open air. The selection and installation of a speaker, as well as its design, should be guided by the problem of coupling an electrical signal source as efficiently as possible to an acoustical load. This involves the determination of the acoustical load or radiation impedances and selection of a diaphragm, motor, and means for coupling the loaded loudspeaker to an electrical signal source. The performance of the speaker is intimately connected with the nature of its acoustic load and should not be considered apart from it.

Radiation impedance

When a vibrating diaphragm is placed in contact with air its impedance to motion is altered, and the added impedance seen by the surfaces which emit useful sound energy is termed "radiation impedance". The radiation reactance is usually positive, and corresponding to an apparent mass. Both reflective mass and resistance as seen by the diaphragm depend on its size, shape, frequency, and the acoustical environment in which it radiates.

Single piston

The average radiation resistance as seen by a flat, circular piston vibrating in air, is nearly proportional to the square of the frequency, provided that the wavelength exceeds the circumference of the piston ($K = 1$). To obtain constant sound pressure within this frequency range, the piston velocity should vary inversely with frequency. This variation in velocity with frequency is usually obtained by placing the fundamental resonant frequency of the diaphragm and motor near the lowest frequency to be transmitted, so that the system is "mass controlled" in this frequency range. When the wavelength of the radiated sound is less than about half the piston circumference ($K = 0.5$) the resistance is very nearly constant at about 41.3 mechanical ohms/sq. cm. At frequencies below $K = 1$, the air loading increases the apparent mass of each side of the diaphragm by approximately the mass of air contained in a cylinder whose base is the piston area and whose height is 0.85 times the piston radius. At high frequencies, the radiation mass ("accession to inertia") and the mass/reactance decreases and approach zero for infinite frequency.

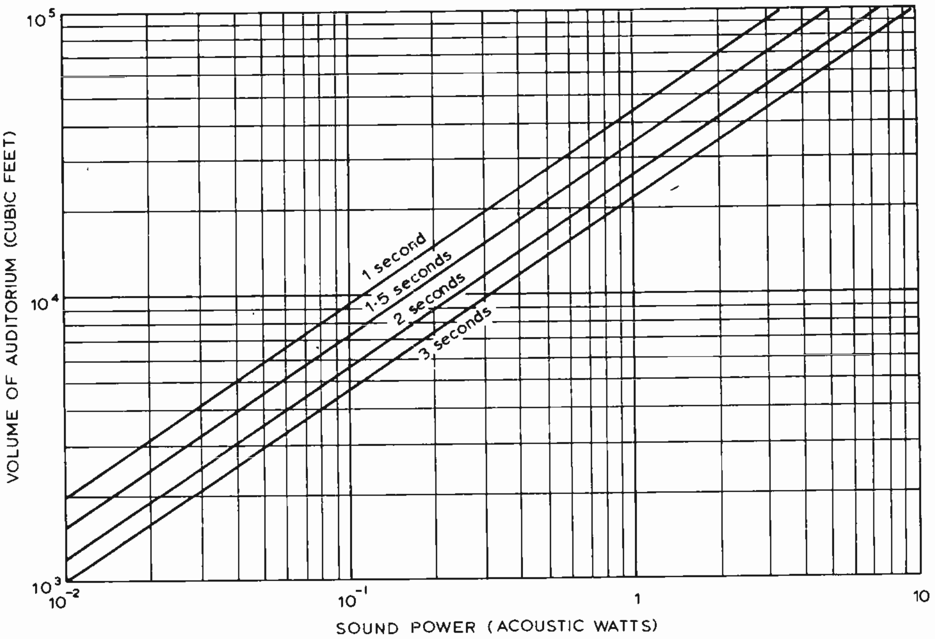


Fig. 2. Power requirements for uniform pressure of +30dB ref. 1μbar (+104dB ref. 0.0002μbar).

Diaphragms

The diaphragm is a mechanical/acoustic transducer which couples the radiation impedance to the speaker motor. With the exception of the electrostatic loudspeaker, the force exerted on the diaphragm is localized, and this force must be transmitted to the acoustic load which is spread over a large area. To do this effectively, the cone is made as rigid and light as possible, and in practical mechanics the cone is the simplest system. The usual conical diaphragm may be thought of as a continuous mechanical transmission line, radiating acoustic energy from each element of area. Radial waves which travel from the driving point to the edge are reflected and circumferential waves which travel around the cone both occur in various combinations, depending on the mode of vibration. The lowest frequency mode, and the simplest one, is that in which the effective radial wavelength of the cone, including the edge termination, is one quarter wave (this must not be confused with a quarter wave length in air at the same frequency). At this frequency, which varies between 500 and 1500 Hz according to diaphragm diameter, no circumferential wave is present and all parts of the cone move in phase. The displacement is maximum at the apex and minimum at the flexible annulus which supports the outer edge and terminates the transmission line. The impedance of this termination plays an important part in diaphragm behaviour, especially at frequencies near the fundamental resonance of the diaphragm and motor and in the 1000 to 2000 Hz range. For this reason, the outer annulus is usually made as resistive as possible, either by doping the surround with material such as polyisobutaline, or using a high dissipation flexible material such as plasticized co-polymers of vinyl chloride and acetate. At frequencies below the lowest mode of the cone itself, all parts of the cone move in phase, unless the annulus stiffness increases rapidly with displacement, in which case the cone may flex at very low frequencies. The annulus is frequently made this way in cheap loudspeakers, to produce distortion of low frequencies and substantially increase their loudness by radiating most of the energy at harmonic frequencies. Unfortunately, intermodulation of low and high frequencies then also occur which in addition to an apparent "full and fruity" bass also results in a strident, shrill high frequency ("Listen to the top!").

Size

It has been found experimentally that the effective area of the cone is its projected or base area. This should not be confused with the advertised diameter of the loudspeaker, which is anything from 1 to 2 inches greater than the effective cone diameter. In direct radiator loudspeakers and at low frequencies radiation resistance is proportional to the fourth power of the radius (square of the area) and the mass reactance to the cube of the radius. The resistance/reactance ratio (or power factor) of the radiation impedance is therefore proportional to piston radius; thus the electro-acoustic efficiency, other factors being constant, at low frequencies increases with diaphragm area. For constant radiated power the piston displacement varies inversely with air, hence "long throw" type of small diaphragm area loudspeakers. With fixed amplitude the radiated power is proportional to the square of the area at a given frequency; or a frequency one octave lower may be reproduced if the area is increased by a factor of 4. The upper limit of diaphragm size is set by increased weight per unit area required to get a sufficiently rigid structure.

Fig. 3 shows the necessary peak amplitude of a piston mounted in an infinite baffle to radiate one acoustic watt of sound power at various frequencies (one side only of the piston radiating). Peak amplitudes in inches are marked on the family of curves; for any other value of acoustic power output (P) multiply peak amplitude by $\sqrt{P}$. From Fig. 2, with an average room of 2000 cu.ft, a reverberation time of one second, and a sound pressure level of +94dB, it will be seen that the total sound output power is of the order of 30 milliwatts. To radiate this power the peak amplitude of a 10-in radiator will be about 0.08in (2mm) whilst a 4-in piston to radiate the same power would require a peak displacement of just over 0.6in (15.5mm). Even with "long throw" loudspeakers it is not possible to obtain a peak-to-peak displacement of $1\frac{1}{4}$in, thus the sound power capabilities must be severely limited at low frequencies. One will often see response curves of these small speakers taken to apparently extraordinarily low frequency limits, but these are always undertaken at low power input levels.

The directional radiation characteristics of a diaphragm are determined by the ratio of the wavelength of the emitted sound to the diaphragm diameter. Increasing the ratio of diaphragm diameter to wavelength decreases the angle of radiation. At frequencies in which the wavelength is greater than four times the diaphragm diameter the radiation can be considered substantially hemispherical, but as this ratio decreases so the radiation pattern narrows. Fig. 4 shows the polar response of a piston in terms of the ratio of diameter over wavelength. This shows the degrees off the normal axis at which the attenuation is 3, 6, 10 and 20 dB (as marked on the curves) as a function of the ratio of the piston diameter over the wavelength of the generated sound wave.

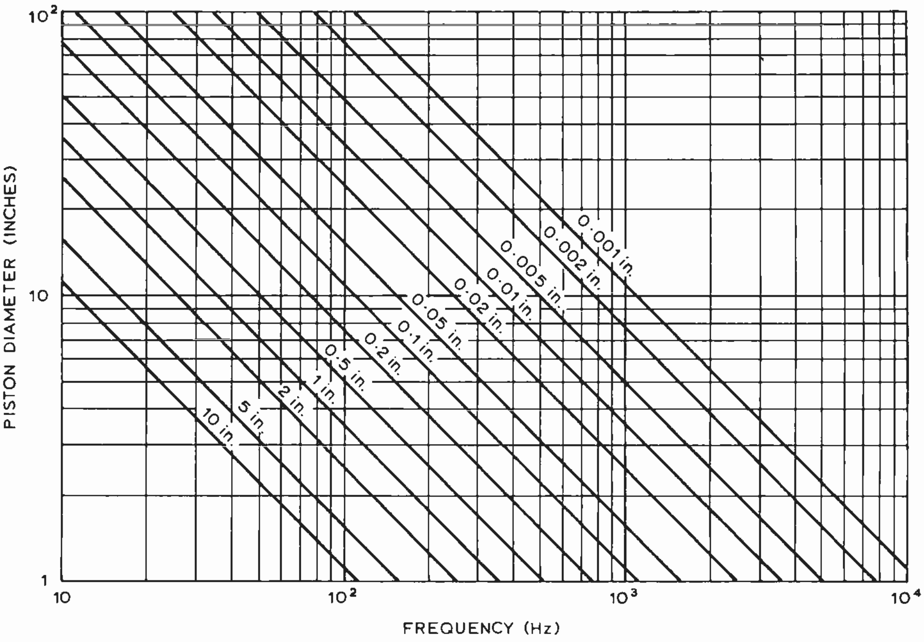


Fig. 3. Peak amplitude of a piston in an infinite baffle to radiate one acoustic watt.

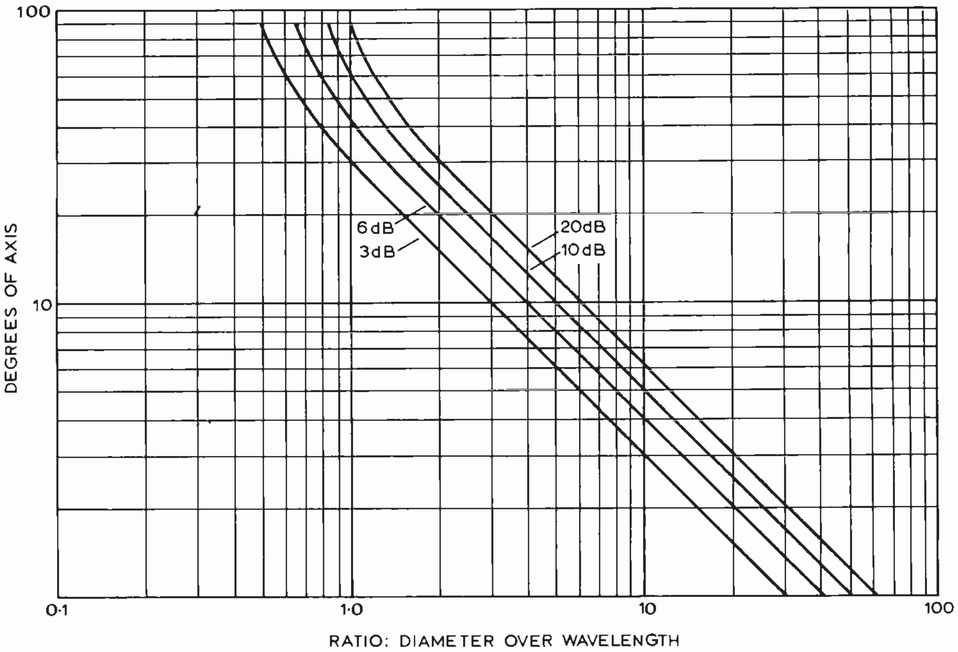


Fig. 4. Directional radiation pattern. Circular piston in infinite baffle.

Shape

The most efficient shape at low frequencies is circular. Theoretically and experimentally investigations have shown that an ellipse with a major minor axis of 2 has an average of 5% to 7% lower radiation resistance in the useful low-frequency range than a circle of the same area; the loss becomes progressively greater as the shape departs still further from circular. The shape of the cross section or profile of the cone depends on the power handling and response desired. Straight-sided cones are usually employed when good 2 to 5kHz response is required and when reproduction above, say, 7kHz may be undesirable. Curved cones improve the response above 6 to 7kHz by providing an impedance viewed from the voice coil which has a more uniformly high negative reactance, and therefore absorbs more power from the high positive reactance due to voice coil mass seen looking back into the voice coil. This improvement is obtained at the expense of response in the 2 to 5kHz region, a weaker cone structure, and reduced power handling in the extreme bass.

Material

Hard impregnated or filled pressed calender papers are used when loudness efficiency and apparent high frequency response are important. The impregnant is usually a hard thermo-setting resin. Radiation response provides very little dissipation in direct radiator cones; hence by using paper having low internal flexural losses the transmission line is made to have strong resonances. The transient response of this type is necessarily poor since non centre moving modes of the cone are unappreciably

continued on page 555

damped by the motor. Soft, loosely packed, felted cones are used when some loss in high-frequency response can be tolerated and a smooth response curve with reduced transient distortion is required. The apparent loudness efficiency of high loss cones of this type are anything up to 6dB lower than that of low loss cones.

In an effort to overcome the intransigencies of paper cones, recourse has been made to other materials. Lightweight metal (aluminium alloys, etc.) immediately springs to mind because of its stability, homogeneity and reproducability but, because of the very low internal frictional losses strong multiple resonances occur in the upper frequencies. A diaphragm of, say, 10 inches in diameter made from 0.003in thick aluminium alloy with a total mass of 40 *g* will show a "ruler" level response up to approximately 2kHz when multiple resonances occur. These are extremely narrow band (in some cases only 1 or 2Hz wide) with an amplitude of anything up to 40dB and an effective *Q* of several hundred. Putting a low-pass filter cutting very sharply at, say, 1kHz does not eliminate shock excitation of these resonances at low frequencies and the result is a "tinny" sound. Reducing the cone diameter and making the flare exponential reduces this effect and also places the resonant frequency a few octaves higher, but does not entirely eliminate the problem. Using foamed plastic materials (and sometimes coating the surfaces with a metal to form an effective girder structure) has met with some success. There are problems associated with the solid diaphragm in that the different finite times for the sound wave to travel directly from the voice coil through the material to the front and along the back edge of the diaphragm to the annulus and then across the front cause interference patterns which result in some cancellation of the emitted sound in the mid upper frequencies, say 800 to 1100Hz. This effect can be mitigated by using a highly damped annulus, with the object of absorbing as much as possible of the "back wave". Expanded polystyrene is the favourite material for these diaphragms although expanded polyurethane has met with some success. An extension of this principle is exemplified in the Yamaha radiators where the diaphragm is almost the full size of the front of the cabinet (say 24 × 18in). In this case the diaphragm, even at low frequencies, does not behave as a rigid piston. The overall performance is impossible to obtain by any mathematical method and must be largely determined experimentally.

The most recent newcomer is vacuum formed plastic sheet cones produced from plasticized polystyrene, polyacetate buterate and similar materials. It is possible to control the internal losses with a fair degree of accuracy and the repeatability is excellent. These form the basis of the cones used in the B.B.C. monitor loudspeakers developed by Harwood. The writer has, however, some reservations on the long term stability, having produced some cones of this material in 1959. After five years (due to the possible migration of the plasticizer, or insufficient forming temperature?) the shape of the cones had distorted and the overall response had changed, although, it must be emphasized, not to the same extent as paper cones under the same conditions!

The annulus of the diaphragm can either be an extension of the cone material itself or, as is more usual with high-fidelity loudspeakers, a highly compliant surround produced from other man made fibres, neoprene or plasticized p.v.c. In the case of woven materials these must be sealed and the sealant is usually used to provide some mechanical termination of the cone. The major restoring force of the loudspeaker is the centre "spider". This is a woven fabric and is impregnated with a thermosetting resin, the weave of the material, number of corrugations, diameter and amount of impregnant determining the stiffness.

The whole structure behaves mechanically as a series resonant circuit. The mass is determined by the weight of the cone, voice coil and former, and the stiffness by the combined effects of the centre spider and the annulus, the *Q* of the circuit being determined almost wholly by the losses of the restoring force.

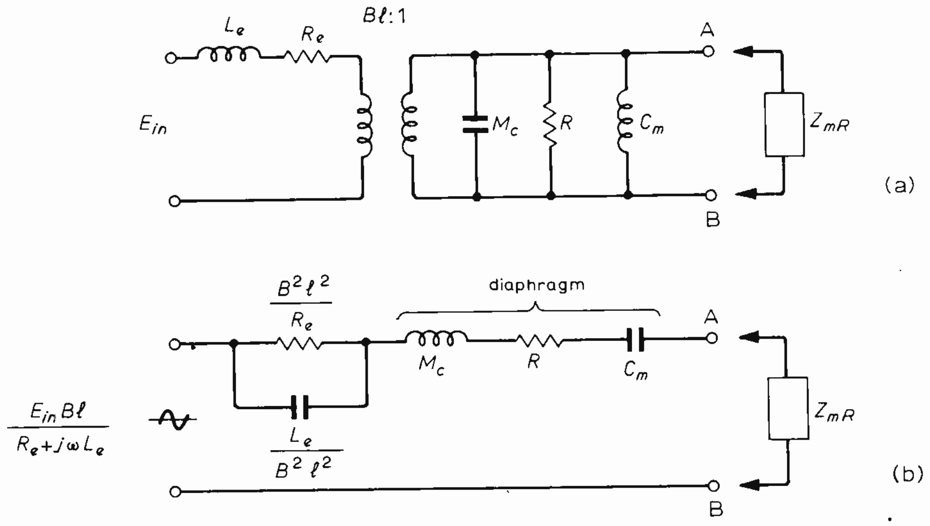


Fig. 5. Analogue of a loudspeaker referred to the electrical side (a) and mechanical side (b).

Motors

A loudspeaker motor converts electrical into mechanical energy and couples it as efficiently as possible to the mechanical impedance seen looking into the diaphragm which it drives. The mechanical circuit of the speaker motor experiences a force when a current is applied to the electrical terminals; the ratio of this force when the mechanical circuit is blocked, to the current which produces it is the force factor, *F*. This is equal to the product of *B* and *l*, where *B* is the average radial flux density which the coil embraces and *l* is the conductor length.

Fig. 5 shows the analogue of a moving-coil transducer referred to the electrical terminals, in which R_e and L_e are the electrical resistance and inductance of the voice coil. The mechanical compliance is reflected back into the electrical circuit as an inductance, the mass as a capacitance and the mechanical losses as a conductance. These together form an electrical resonant circuit and represent the motional impedance of the speaker with no acoustic loading (i.e., in a vacuum). The acoustic loading can be represented as a capacitance in series with a resistance which are not necessarily constant with frequency. The art in motor design is to get the largest *Bl* factor with the lowest weight of magnet and because of magnetic fringing around the pole pieces the voice coil can be wound slightly greater in length than the top pole face to obtain maximum utilization of the magnetic field. But because of the non-linearity this can only be used where the movement of the voice coil is small, otherwise the coil moves out of the linear magnetic field, resulting in harmonic distortion. To overcome this, the voice coil can either be wound considerably longer than the magnet top plate or considerably shorter. This latter is rarely used nowadays because the resultant efficiency and power handling capacity is reduced.

The diameter of the voice coil is determined almost wholly by the power handling requirements of the loudspeaker. A maximum dissipation of a ½-in voice coil is generally of the order of 1 watt, whilst a 2-in voice coil wound on a black anodized aluminium former with a maximum clearance of 0.005 in from the pole faces would be able to dissipate approximately 25 watts, but this value must be taken with some reservation, depending on the adhesives used and the method of winding. For high-power dissipation, voice coil diameters of 3 or 4 inches are almost mandatory, although of course it is possible to use multiple radiators to spread the dissipation.

Efficiency/frequency characteristic

The efficiency of a loudspeaker is the ratio of useful acoustic energy output to electrical signal energy input. The "absolute" or system efficiency is the ratio of the useful acoustic energy output to the signal energy an ideal load would absorb from the signal source. This definition is a practical one, in that it penalizes the speaker for its inability to absorb maximum power from the source because of variations in its own electrical impedance. At the resonant frequency of the speaker the two efficiencies can differ by a factor of 10 or more.

Absolute efficiency =

$$\left| \frac{4 r_s M^2 r_r}{[Z_e + M^2/Z_m]^2 Z_m^2} \right|$$

where Z_e = blocked voice coil impedance plus r_s, Z_m = total mechanical impedance of the mechanical mesh including diaphragm radiation and air load, r_r = total radiation resistance seen by the diaphragm, r_s = generated resistance plus voice coil resistance, M = force factor ($B\ l$).

The mid-range efficiency of speakers commonly used in hi-fi varies from 0.5 to about 5%. Efficiencies of horn-loaded units can be as high as 30% although this is difficult to achieve over any appreciable frequency range.

Baffle loudspeakers

The baffle is a partition which may be used with an acoustic radiator to increase the effective length of the transmission path between the front and the back of the radiator. The larger the baffle the greater the path length between the front and the back of the loudspeaker diaphragm and the lower the frequency at which cancellation between the (out of phase) radiation from the front and the back faces of the loudspeaker cone occur. Generally, this type of "enclosure" is confined to large diaphragm electrostatic and similar loudspeakers which act as a doublet source, and, unless the diaphragm area is very large, low frequency response, especially below 100Hz, can be disappointing.

Infinite baffle

This is a total enclosure which prevents radiation from the back side of the diaphragm. When the wavelength of the radiated sound exceeds four times the maximum enclosure dimension the enclosure adds a total stiffness (S) viewed from the diaphragm

$$S = \rho c^2 A_d^2 / V_0 \text{ dyne/cm}$$

where A_d is the effective piston area of the cone, and V_o is the equilibrium volume of the cone.

The acoustic "capacitance" is the reciprocal of this value. The stiffness increases the natural resonant frequency of the loudspeaker. If the enclosure includes absorbing material, this stiffness will be altered by the reactance seen at the surface of the material. Each sq. cm will dissipate:

$$P^2 \times \frac{10^{-7}}{r_B} \text{ watt}$$

where P= sound pressure in the box and
r= $_B$resistance per unit area for sound of normal incidence on the absorbing material.

If the volume of the box is small enough, or the free resonance of the speaker is low enough, the enclosure and not the diaphragm stiffness will control the resonant frequency. Ideally, for optimum low-frequency response, the reflected compliance due to the cabinet stiffness as seen at the driving point should equal the circuit compliance of the loudspeaker, and the following equation details the optimum constant:

$$D = 0{\cdot}88 \sqrt{\frac{V}{C_m}}$$

where d=diaphragm diameter in inches, V = volume in cu. ft and C_m = loudspeaker compliance in metres/newton

Taking a 10-in radiator, a resonant frequency of 50Hz, and a compliance of 10^{-3} metres/newton, the optimum enclosure volume will be 16 cu. ft. This is somewhat large, even for the most ardent hi-fi enthusiast, especially when four enclosures will be required for quadraphonic sound!

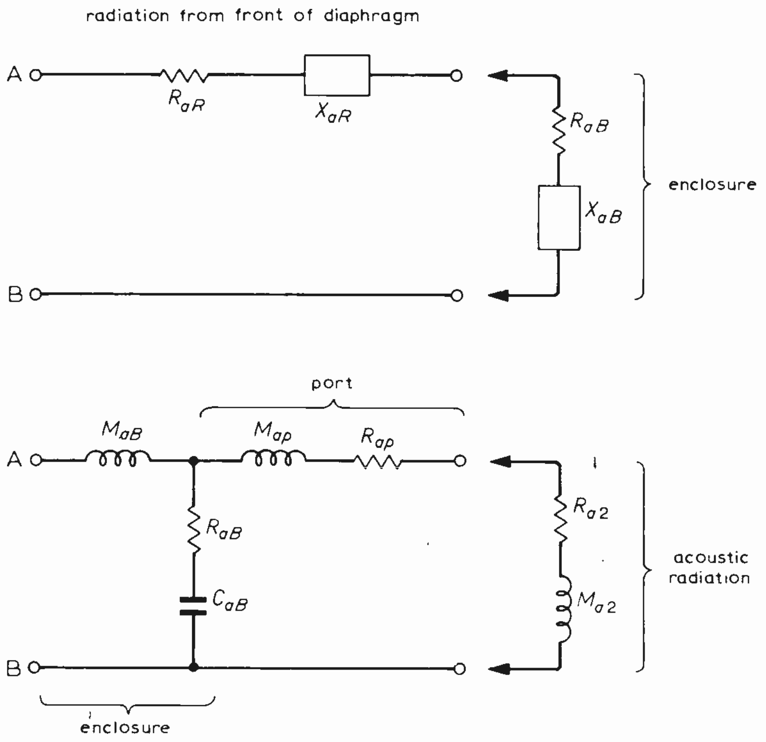


Fig. 6. Analogue of simple enclosure.

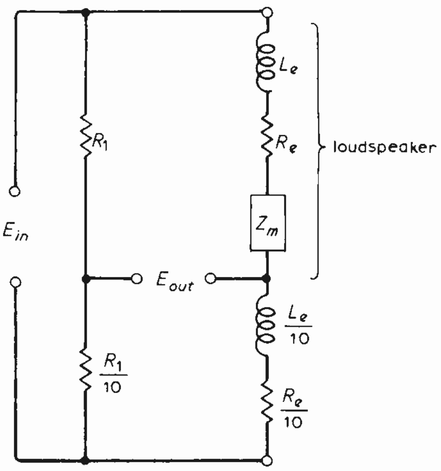


Fig. 7. Bridge circuit where E_{out} is proportional to coil velocity.

Reflex enclosures

One method of minimizing this difficulty is to use a reflex cabinet where some of the latent energy available from the rear of the diaphragm can be made available at low frequencies. The reflex enclosure is a closed box with a hole or tunnel in one (usually the front) wall. The area of the port is equal to or smaller than the effective area of the driving unit. Fundamentally, this system is nothing more nor less than a Helmholtz resonator. The addition of a port behaves as a second diaphragm since an effective mass of air oscillates in the opening. Ideally, the total dynamic mass in the port should equal the effective mass of the diaphragm and voice coil but, especially with small cabinets, this leads to an impracticably large tunnel, and, of recent years, the addition of a passive diaphragm in place of the tunnel is used to obtain the correct mass loading.

Fig. 6 shows the analogue of a vented enclosure in which it is seen that the mass of the port is in parallel with the stiffness of the enclosure, and the low-frequency output is augmented by this extra resonant mesh. Care must be taken that adequate damping is provided inside the enclosure otherwise the system will "ring" at the various resonances.

Transmission-line speaker

The phase and amplitude of the back side radiation of a cone may be altered by coupling a conduit or acoustic transmission line to it. In earlier times, the multiple resonant properties of such a

continued on page 557

line were used to influence the response. In more recent examples, generally known as "labyrinth", the line is folded to conserve space and made highly dissipative. Phase shift between the diaphragm and the port or open end is due to the time of transmission in the line. At very low frequencies the line is a small fraction of a wavelength long, the phase shift is negligible, and the port and diaphragm ratio are out of phase. When the line is a quarter wave long, it acts as an impedance inverter and the cone sees a high impedance and the radiation from the port is at maximum. Non-linear distortion is therefore reduced at and near this frequency. It is usual to arrange for the resonant frequency of the loudspeaker to be at this frequency to aid damping. Between this frequency and the one for which the line is a half wavelength long the port phase shifts gradually to maintain some component of its radiation in phase with the diaphragm. Because of the infinite series of resonant and anti-resonant frequencies of the line, high absorption must be introduced to prevent the production of objectionable resonances and radiated out of phase components of the port. Generally, the design arranges for total absorption of back radiation for frequencies in excess of a few hundred Hz.

Small speaker enclosures

As already stated, the smaller the enclosure, the higher the low resonant frequency below which the acoustic power output drops at 12dB per octave. If the loudspeaker system is made part of the feedback network and sufficient power is available from the amplifier, it is possible to extend the low frequency performance considerably. This is now becoming familiar under the name of motional impedance feedback loudspeakers, servo controlled systems, etc. The system is by no means new and was described by D. T. N. Williamson in *Wireless World*, October 1947. Fig. 7 shows the system in which the loudspeaker forms one arm of a bridge, in which balance is achieved with the voice coil blocked. Thus an e.m.f. generated by movement of the coil may be fed back degeneratively to the input of the amplifier. The system (with modifications) works exceptionally well, is now being applied to commercial speakers and an extension of the low frequency response by up to an octave is obtained.

Multiple speaker enclosures

It is generally considered impossible for one loudspeaker element to cover the full frequency range, handle relatively high powers and have an extended frequency response. To this end, the frequency spectrum is divided into two and sometimes three or more bands. The low-frequency unit covers up to frequencies of the order of 1 or 2kHz, and the high-frequency unit takes over at that frequency. If more than two elements are used the frequency band is subdivided still further. Electrical networks are used to separate the electrical input to the loudspeakers into their respective frequency bands. The simplest consists of a series inductance for the low-frequency unit and a series capacitance for the high-frequency unit. The slope at cross-over frequency will be 6dB per octave in terms of crossover frequency f and loudspeaker impedance Z,

$$C = 1/2\ \pi f$$

$$\text{and } L = Z/2\ \pi f$$

This is a quarter section network.

For many applications this rate of slope is insufficient and half section networks giving a slope approaching 12dB per octave are used. The parallel arrangement shown in Fig. 8(a) comprises two identical arms in parallel, each consisting of an inductance and capacitance in series. The treble unit is connected across the inductance in one arm and the bass unit across the capacitance in the other. The value of both inductances is

$$L = Z/2\ \pi f$$

and the value of both capacitances is equal to:

$$C = \frac{1}{2\sqrt{2}\pi f Z}$$

The corresponding series circuit is given in Fig. 8(b) and the values are

$$L = \frac{Z}{2\sqrt{2}\pi f Z}$$

$$C = \frac{1}{\sqrt{2}\pi f Z}$$

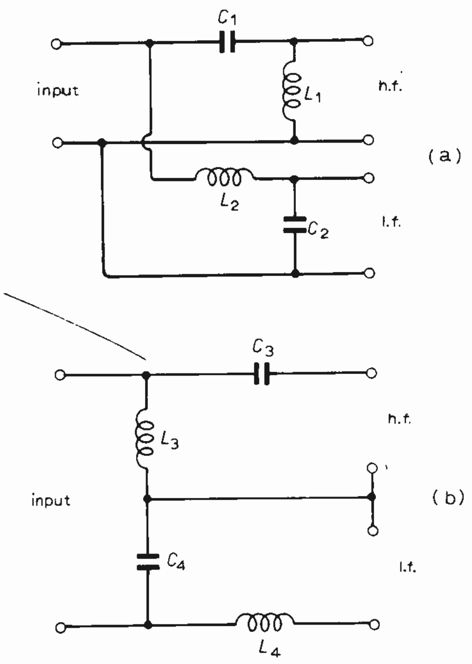


Fig. 8. Parallel (a) and series (b) cross-over networks.

Commercial loudspeakers

With so many options open to the designer it is very difficult to generalize, but for domestic hi-fi listening one of the most satisfactory approaches is that based on the B.B.C. monitor systems. A number of manufacturers are producing designs more or less in accordance with this system. Fig. 9 shows parameters of the Mordaunt Short MS235 enclosure and Fig. 10 the Spendor. An entirely different approach is the large-diaphragm open-backed doublet radiator produced by Yamaha, shown in Fig. 11.

Measurements

The assessment of loudspeaker performance probably causes more controversy

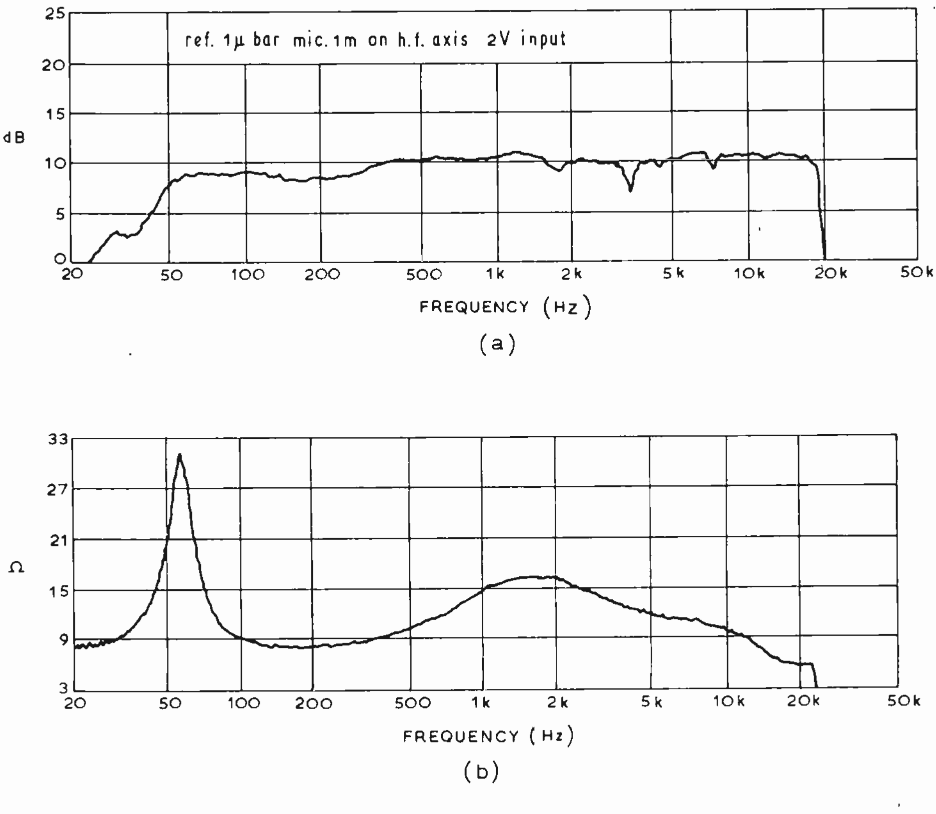


Fig. 9. Mordaunt-Short MS235 enclosure: (a) free-field response; (b) input impedance.

amongst engineers than any other facet of sound reproduction. Frequency response is generally measured with a microphone on the axis of the high-frequency radiator and polar response is obtained by rotating the speaker about its vertical axis. These measurements are made under free-field conditions, generally in an anechoic chamber, and although they give the designer a basis for evaluation they do not represent the facts of life under domestic user conditions. A system devised by Philips with the speaker fed by pink noise and the output analysed into third-octave sections and integrated over an appreciable area of the room gives an overall response more in keeping with user conditions when measured in normal domestic living rooms. In fact, correlation above a few hundred Hz is exceptionally close. With present day systems it is possible to get a steady-state response flat within ±2dB from well below 100Hz to 20 kHz and for this response not to vary by a further −3dB over a solid angle up to 90° or 100° to frequencies in excess of 16kHz.

At the other end of the scale, there are many loudspeakers at the cheaper end of the range with a frequency response "flat" ±15dB extending from 300Hz to 3kHz; but notwithstanding the purist attitude, they represent value for money and give pleasure to a large section of the public.

A table summarizing commercially available loudspeaker enclosures starts on page 559 and will be continued in the December issue.

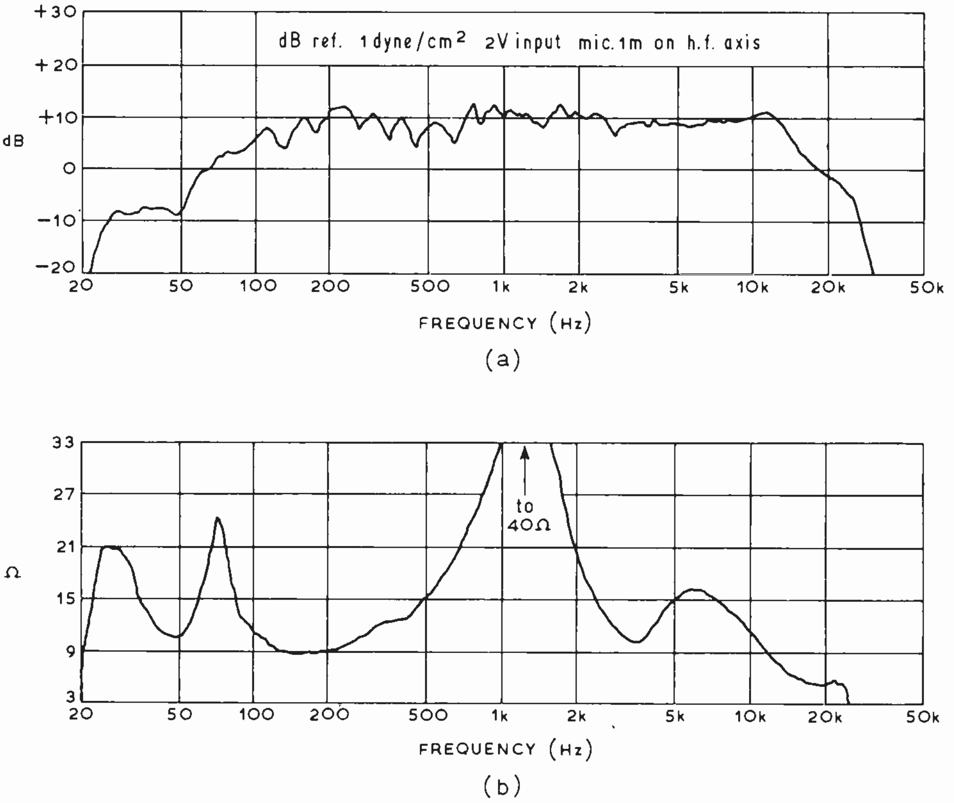


Fig. 10. Spendor enclosure: (a) free-field response (b) input impedance.

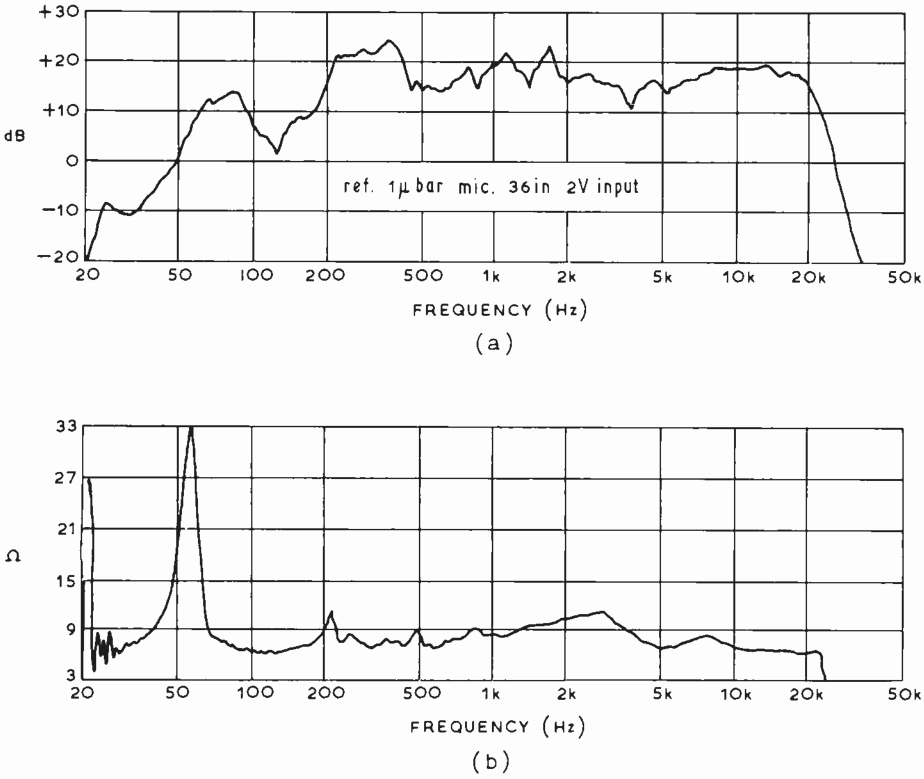


Fig. 11. Yamaha NS-250 E: (a) free-field response — treble maximum; (b) input impedance — treble maximum.

Design of enclosures at l.f.

A lecture given in the recent programme of the British Section of the Audio Engineering Society throws interesting light on the fundamental design of low-frequency direct-radiator loudspeaker systems. Given by Richard Small of the School of Electrical Engineering at the University of Sydney, the paper represented a discussion of the findings of an extensive research programme into the subject. Based on the work of Henry Kloss of Acoustic Research, the theory assumes that at low frequencies loudspeakers behave as high-pass filters. From this it can be deduced that the efficiency in converting electrical to acoustic energy can be defined as a function of frequency, but above the low frequency cut-off a constant relationship ensues to the limit of the driver piston range. It has been found that for small-signal conditions the reference efficiency (E_R say) is proportional to the cube of the cut-off frequency (f_o say) defined as the point at which the efficiency drops 3dB below the reference, and directly proportional to enclosure volume (V say) with a constant of proportionality (efficiency constant" or k_E) depending on the type of enclosure. Typical values of the efficiency constant for "well-designed enclosures" were given by Small as approximately 1×10^{-6} for sealed enclosures and 2×10^{-6} for vented and passive radiator systems of the type referred to in our survey. For an enclosure of average size — about two cubic feet and an l.f. cut off of 40Hz – the reference efficiency would be around 0.35% for a sealed box and 0.7% for a vented enclosure.

For large-signal conditions, Small has established that the displacement-limited acoustic power of a system is proportional to the fourth power of cut-off frequency and to the square of the air volume displaced with a constant of proportionality (say k_p) depending on the system type. Thus the electrical input required to produce this power is

$$P_E = \frac{k_p}{k_E} \cdot f_0 \cdot \frac{V_D^2}{V}$$

The three relations form a predictable synthesis technique for loudspeaker units at l.f.

Loudspeaker enclosures available in the U.K.

Model	Power rating (W)	Size (in)	Impedance (Ω)	Drive units	Finish	Price	P. Tax
A.E.G. (Great Britain) Ltd, 27 Chancery Lane, London WC2							
Telefunken							
L250	35	18 x 7⅛ x 12¾	4	3	Walnut	44·95	Tax inc.
TL41	15	6½ x 8 x 10½	4	2	White	23·75	,, ,,
L55	20	8½-in dia.	4	1	Aluminium	17·25	,, ,,
TL30	15–20	6¼ x 3 x 20¾	4	3		27·95	,, ,,
L205	35–50	18 x 7 x 12¾	4	3		29·75	,, ,,
L60	15–40	18½ x 7¾ x 10½	4	2		25·95	,, ,,
Acoustical Manufacturing Co. Ltd, St Peter's Road, Huntingdon							
Quad							
Electrostatic	15	34½ x 10½ x 31	15–30	1	Bronze	72·00	—
Acoustico Enterprises Ltd, 6 Union Street, Kingston-upon-Thames, Surrey							
Heco							
P2000	30	14 x 8½ x 7	4–8	2	All teak or rosewood	53·72	Tax inc.
P3000	35	15¾ x 8½ x 7	4–8	3		58·75	,, ,,
P4000	40	18 x 9¾ x 7¾	4–8	3		67·14	,, ,,
P5000	50	23½ x 12½ x 9¾	4–8	4		92·86	,, ,,
P6000	60	14 x 30¾ x 10½	4–8	4		125	—
SM525	25	15 x 8½ x 7	4–8	2		25·18	Tax inc.
SM535	35	17 x 9½ x 7¾	4–8	2		33·57	,, ,,
SM540	40	22 x 11 x 7¾	4–8	3		45·32	,, ,,
Acoustic Research International, High Street, Houghton-Regis, Beds.							
AR4X	15	10 x 18¾ x 9	8	2	All walnut	32	Tax inc.
AR6	20	12 x 19½ x 7	8	2		39·90	,, ,,
AR2AX	20	13½ x 23¾ x 11½	8	3		59·50	,, ,,
AR3A	25	14 x 25 x 11½	4	3		100	—
ARLST	64	27 x 20 x 9¾	4	9		200	—
Adastra Electronics Ltd, Unit N.22, Cricklewood Trading Estate, Claremont Road, London NW2 1TU							
S.D.L.							
Courier	15	10½ x 7¼ x 15	8	1	All teak	31·50*	—
Envoy	15	10½ x 7¼ x 18	8	2		40·00*	—
Consul	20	15 x 10¼ x 21	8	3		32·00	—
Diplomat	50	18 x 14 x 27	8	4		64·00	—
Ambassador	50	19¼ x 12 x 36	8	5		85·00	—
* Per pair							
Alba (Radio & Television) Ltd, Tabernacle Street, London EC2							
UA300	15	8⅜ x 7 x 16¾	8	2	Teak	21·20	3·40
Richard Allan Radio Ltd, Bradford Road, Gomersal, Cleckheaton, Yorkshire BD19 4AZ							
Minette	10	7 x 6¼ x 11½	8	2	Teak	14·25	2·20
Chanconne	10	12 x 9 x 20	8	2	Teak	17·25	2·66
Flamenco	15	12 x 8½ x 20	8	3	Teak/walnut	25·00	3·86
Pavane	15	15½ x 12 x 25½	8	3	Teak	35·25	—
Super Sarabande	20	18 x 17¼ x 32½	8	3	Teak	61·00	—
High Fidelity Module*	10	7 x 6¼ x 11½	8	2		9·35	1·44
Twin*	10	12 x 9 x 20	8	2		8·95	1·38
Triple-8*	15	13 x 8½ x 20½	8	3		13·50	2·08
Triple*	20	15½ x 12½ x 25	8	3		20·35	—
Super Triple*	25	13 x 8½ x 20½	8	3		24·00	—
*Kit							
A.S. Techniques, 101 London Road, Leicester							
Astec 15	15	25½ x 13½ x 9	8	1		38·75	Tax inc.
Astec 10	15	17½ x 11 x 9	8	1		29·50	,, ,,

Model	Power rating (W)	Size (in)	Impedance (Ω)	Drive units	Finish	Price	P. Tax
Audix B.B. Ltd, Stanstead, Essex							
SM100	100	33¼ x 19 x 15¼	8	3		92·40	—
L470	8	48 x 7 x 4	8–15	7	All afrormosia	48·10	—
L408	40	84 x 12 x 5	100-V	7		68·30	—
L206/HZ	20	36 x 10½ x 5	100-V	7		39·20	—
L206/15	20	36 x 10½ x 5	15	7		35·10	—
L204/7	7	24¼ x 6¼ x 4	7·5	7		15·20	—
L204/HZ	7	24¼ x 6¼ x 4	100-V	7		16·90	—
Baker Reproducers Ltd, Bensham Manor Road Passage, Thornton Heath, Surrey							
Major Module*	20	12 x 19 high	15–16	2	All teak	11·50	—
De Luxe	15	16 x 12 x 27	15–16	1		20·00	—
Superb	15	16 x 12 x 27	15–16	1		25·00	—
*Baffle. Also in kit form							
Bang & Olufsen U.K. Ltd, Eastbrook Road, Gloucester GL4 7DE							
2500	50	3¾ x 3¾ x 3¾	4	6	Black/chrome	46·04	7·86
1700	15	7 x 7 x 13¼	4	2	All teak or rosewood †	42·62	7·28
1800	15	17 x 4 x 13	4	2		46·90	8·00
2700	20	8 x 8 x 16¼	4	2		56·29	9·61
3700	40	9½ x 9½ x 19¾	4	2		68·25	11·65
4700	50	11½ x 11½ x 22¾	4	4		84·99	14·51
5700	60	14¼ x 11¾ x 26	4–8	3		127·70*	21·80
* Per pair. † Rosewood extra.							
F. W. O. Bauch Ltd, 49 Theobald Street, Boreham Wood, Herts.							
OY	35	19 x 12 x 9	*	3	Walnut	245·00	—
* Built-in 30-W amplifier.							
Boosey & Hawkes (Sales) Ltd, Sonorous Works, Deansbrook Road, Edgware, Middx.							
Jordan-Watts							
Jumbo	12	8 x 3½ x 16½	*	1	Teak	21·60	—
Janet	12	8 x 6 x 12	*	1	Teak	21·60	—
Juliet	12	10 x 9 x 16	*	1	Teak	28·20	—
Juno	12	12 x 6½ x 24½	*	1	Teal	28·20	—
Gemini	25	13½ x 7½ x 30	*	2	Walnut	44·40	—
Jupiter	25	15 x 10½ x 24½	*	2	Walnut	56·40	—
GT	15	12¾ x 6½ x 26¾	*	2	Teak	34·50	—
Jodrell	30	13½ x 8¾ x 30	*	2	Teak/walnut	51·30	—
* 3–5, 7½–15, 15–16 Ω as required							
Cambridge Audio Ltd, The River Mill, St. Ives, Hunts.							
R40	40	31¼ x 13 x 12¾	8	3	Both teak	68·50	—
R50	50	41½ x 17⅝ x 13	8	4		98·00	—
City Audio Services Ltd, 7 Chalcot Road, London NW1							
CA/11	10	11½ x 8 x 18½	8	2	All teak	15·75	—
CA/15	15	11½ x 8 x 18½	8	2		18·50	—
CA/20 Mk.III	12	11½ x 8 x 18½	8	2		23·30	—
Crown Radio Co. Ltd, 128 Shoreditch High Street, London E1 6JE							
CSP12	8	17½ x 7¼ x 9¾	8		Both walnut	29·50 *	
CSP13	10	21 x 9 x 10½	8			39·50 *	
* Per pair							
Denham & Morley (Overseas) Ltd, 453 Caledonian Road, London N7							
JVC							
GB1E	40	13½ dia.	8	8		105·40	14·57
5335	40	14½ x 11½ x 25½	8	3		96·50	—
5390	50		4	2		46·75*	6·46
5395	20	10½ x 8½ x 18½	8	2		55·50*	7·67
* Per pair							

Model	Power rating (W)	Size (in)	Impedance (Ω)	Drive units	Finish	Price	P. Tax
Decca Radio & Television, Special Products Division, Ingate Place, Queenstown Road, London SW8							
Decca-Kelly							
Deram	8	13¾ x 8 x 25	15	2	Both teak	21	Tax inc.
Apollo	30	17 x 12 x 28	8–15	2		58	,, ,,
Dynatron Radio Ltd, St. Peter's Road, Maidenhead, Berks, SL6 7QY							
LS1034T	8	13⅞ x 7½ x 10¼	4	2	Teak	15·08	2·42
LS1434T	10	11⅞ x 10¼ x 19¾	4	2	Teak	16·80	2·70
LS1638T	15	11 x 9¼ x 19¾	4–8	3	Teak	24·99	4·01
LS1734	10	11⅞ x 10¼ x 19¾	4	2	White	16·80	2·70
LS2034T	10	10¼ x 15½ x 26⅞	4	2	Teak	22·40	3·60
LS2528	15	16¾ x 12 x 27	4	2	Walnut	32·74	5·25
LS2828	15	16¾ x 12 x 27	4	2	Mahogany	32·74	5·26
LS3034T	15	14⅜ x 12 x 26½	4	2	Teak	24·99	4·01
LS4038T	40	14⅜ x 12 x 26½	4–8	3	Teak	42	—
LS2638	40	17¾ x 12¾ x 27¼	4–8	3	Walnut	52·50	—
Eagle International, Heather Park Drive, Wembley, Middx., HAO 1SN							
AA14	25	13x11½x24½	8	3	All teak	38·60	—
DL25	4	140x120x230mm	8	1		8·39*	1·41
DL42	6	150x165x250mm	8	2		10·19	1·71
AA16	8	224x160x360mm	8	3		20·80*	3·50
DL67	10	220x170x300mm	8	2		15·61	2·79
*Per pair							
Electro-acoustic Industries Ltd, Stamford Works, Broad Lane, London N15							
E6S	10	11 x 8 x 6	8	1	Teak	10	1·62
E.M.I. Sound Products Ltd, Blyth Road, Hayes, Middx.							
LEK150	8	17 x 7¾ x 10½	8			25·90*	—
LEK215	25	28½ x 15 x 14½	8			51·00	—
LEK250	8	13¾ x 7¾ x 6¾	8			21·20*	3·61
LEK315	35	33 x 15 x 20	8			83·40	—
LEK350	15	23¾ x 11⅞ x 15	8			24·75	—
LEK450	8	18 x 9½ x 11	8			29·20*	—
LEK650	6	18 x 9½ x 11	8			32·40*	5·67
LEK850	10	14 x 7¾ x 9	8			25·44*	4·39
LEK750	15	28½ x 15 x 14½	8			43.00	—
All available in kit form. * Per pair							
Europa Electronics, Howard Place, Shelton, Stoke-on-Trent, Staffs.							
Korting							
LSB25	15	11½ x 21½ x 5	4·5	2	All walnut	25	3·61
LSB30	45	13¾ x 25½ x 8½	4·5	3		35	5·06
LSB65	45	13¾ x 25½ x 7¾	4·5	4		49·75	—
Expotus Ltd, 10 Museum Street, London WC1							
Bose							
501	100	14½ x 14½ x 24	4	2	Both walnut	150*	—
901	100	20⅝ x 12¾ x 12⅞	8	9		250*	—
* Per pair							
Farnell-Tanberg Ltd, 81 Ki..stall Road, Leeds LS3 1HR							
Hi-Fi System 18	20	9¼ x 9¼ x 4¼	4	2	All teak*	18·83	3·17
Hi-Fi System 11	20	12⅝ x 8½ x 6	4	2		17·12	2·88
Hi-Fi System 12	25	17 3/16 x 8 3/16 x 7½	4	2		18·83	3·17
Hi-Fi System 7	20	20½ x 10¼ x 10	3·2	2		25·25	4·25
TL12	25	16¼ x 9¼ x 7½	4	2		23·75	4·00
TL25	35	20¾ x 11⅝ x 8 11/16	8–4	2		30·60	5·15
TL50	45	25⅝ x 14 9/16 x 11	8–4	3		68·00	—
TAN16						7·27	1·23
* Rosewood extra							
Jonathan Fallowfield Ltd, Strathcona Road, North Wembley, Middlesex HA9 8QL							
Yamaha							
NS410	25	12 x 7 x 19	8	2	Teak	50*	Tax inc.
NS230E	25	14 x 7 x 21	8	2	Rosewood	75·75*	—
NS250E	40	23½ x 16½ x 7½	8	2	Rosewood	102·96*	—
NS18	45	21¼ x 10 x 28¼	8	2	Rosewood	155·38*	—
* Per pair							

Model	Power rating (W)	Size (in)	Impedance (Ω)	Drive units	Finish	Price	P. Tax
Feldon Audio Ltd, 126 Great Portland Street, London W1N 5PH							
JBL							
Aquarius 4	25	40 x 10 x 10	8	2	Walnut	88	—
Century L100	50	24 x 14 x 13	8	3	Walnut	144	—
Prima L125	35	15½ x 19 x 14⅞	8		Various	65	—
Studio L200	100	32¾ x 24 x 21⅛	8	2	Walnut	328	—
The Ferrograph Company Ltd, The Hyde, Edgware Road, Colindale, London NW9							
S1	25	25 x 14 x 17½	8	3	Teak	95	—
Goodmans Loudspeakers Ltd, Downley Road, Havant, Hants PO9 2NL							
Mezzo 3	30	12 x 9 x 19½	4–8	2	Teak or walnut	35·70	—
Magnum K2	40	15 x 11¼ x 24	4–8	3	Teak or walnut	46·20	—
Minster	20	19 x 10½ x 10	4–8	2	Teak/walnut/white	21·06	3·54
Magister	50	27 x 20 x 14	4–8	3	Teak or walnut	65·63	—
Havant	20	18¾ x 10½ x 10½	4	3	Teak, walnut or white	24·44	4·12
Double Maxim	30	17¾ x 6¾ x 7½	4	3	Teak, walnut or white	28·84	4·86
Dimension-8	60	30⅜ x 14 x 12½	4	8	Teak or walnut	72·44	—
Grundig (Great Britain) Ltd, Newlands Park, London SE26							
Troika 3012/3022	25/35	21 x 5 x 13¾	4–5	5	Black	87·69*	14·06
Troika 7301	30/40	21 x 5 x 13¾ plus two 5½-in cubes	4–5	5	Teak bass, grey/white treble		
7000	50	12¾-in dia.	4	12	White		
303M	25	20 x 13½ x 3¼	4	3	White		
210	15	7½-in dia.	4	2	Satin chrome and black		
* Per pair							
Hacker Radio Ltd, Norreys Drive, Cox Green, Maidenhead, Berks SL6 4BP							
LS500C	12	10¾ x 8½ x 16½	8	2	All teak	21·50	—
LS1000D	15	13¼ x 11¼ x 20¼	8	2		27·00	—
LS1500B	20	15½ x 12 x 30	8	3		48·00	—
P. F. & A. R. Helme Ltd, Summerbridge, Harrogate HG3 4DR. Yorks.							
Linnet	15	12 x 8 x 7	8 or 4	1	All teak	11·60	1·93
Firecrest	20	14 x 9 x 7½	8 or 4	2		21·20	3·53
Swift	20	18 x 10 x 9	8 or 4	2		23·60	3·92
Swallow	50	20 x 11 x 9	8 or 4	2		28·00	4·66
Oriole	50	28 x 16½ x 12	8	3		59·50	—
System PR.202	30	20 x 11 x 9	8 or 4	2		29·00	4·82
System PR.203	40	20 x 11 x 9	8 or 4	3		35·60	5·92
Highgate Acoustics, 184 Great Portland Street, London W1							
Alpha							
HT7 Mark II	10	11¼ x 17½ x 7	8	2	Teak or walnut	18·96	3·04
HT10 Mark II	20	17 x 22⅞ x 5⅛	8	2	Teak or rosewood	20·68	3·32
HT16	10	11 x 15½ x 7	8 & 4	1	Teak	10·34	1·66
HT17 Mark II	10	10 x 13 x 4½	2	2	Teak or walnut	12·93	2·07
HT20 Mark II	20	11¼ x 17½ x 9¼	8	3	Teak or walnut	24·99	4·01
HT30	15		8	3		14·65	2·35
Luxor							
KH520	15	8½ x 7½ x 10	4	2	Teak/rosewood	13·79	2·21
SH104	40	12½ x 10 x 22	4	2	Teak/rosewood	31·45	5·05
SH835	40	18-in high 13-in dia.	4	2	Teak	50·84	8·16
KH501	10	19 x 22 x 10	4	1	Teak/rosewood	9·48	1·52
KH821	20	27 x 40 x 19	4	2	Teak/rosewood	19·39	3·11
Harman Kardon							
HK50	—	11½ x 12 x 18	6	2	Walnut	70·84	8·16
Citation 13	60	20⅝ x 14¾ x 29½	6	3	Walnut	150·80	24·20

To be concluded

Model	Power rating (W)	Size (in)	Impedance (Ω)	Drive units	Finish	Price	P. Tax
Howland- West Ltd							
Luxman							
LX77	30	26¼ x 15½ x 12¼	8	3	Rosewood		
IMF Products (G.B.), Westbourne Street, High Wycombe, Bucks							
Compact	18	16½ x 10½ x 10	8	3		60·00*	9·98
ALS40	25–60	13½ x 3½ x 26½	8	4		144·62*	20·62
Monitor	25	40 x 17½ x 19¾	8	4		275·00*	—
Studio	20	36 x 14 x 15	8	4		195·94*	27·94
Professional	100	42 x 17½ x 19¾	8	4		350·00*	—
* Per pair							
ITT Consumer Products (U.K.) Ltd, Foots Cray, Sidcup, Kent DA14 5HT							
KS653	7	15¾ x 9⅞ x 6	8	1	Simulated/teak	14·85	2·84
KS656	6	9¼ high, 9 dia.	8		Black moulded	7·29	1·42
KS657	6	11¼ x 7 x 5	8		Simulated/teak	9·03	1·76
KS658	15	18 x 11½ x 6⅞	8	2	Simulated/teak	20·14	3·92
KS659	18	27½ x 11 x 9½	4	3	Simulated/teak	34·93	6·78
KS660	20	27¾ x 16 x 9½	4	3	Teak	45·34	—
Kirkman, 40 The Broadway, Crawley, Sussex							
Mk 2		31 x 18 x 8½	7–15	3		52·00	Tax inc.
KEF Electronics Ltd, Tovil, Maidstone, Kent							
Cresta	15	13 x 7 x 9	4–8	2	Teak or walnut*	20·84	3·47
Celeste Mk 2	30	18 x 6 x 10¾	15	2	Teak or walnut*	30·00	—
Concerto	25	17 x 12 x 28	8	3	Teak or walnut*	58·50	—
Chorale	20	18½ x 8⅝ x 11	8	2	Teak or walnut*	28·50	4·47
Cadenza	25	23½ x 14¼ x 11¾	8	2	Teak or walnut*	46·75	—
Coda	15	9 x 5¾ x 13	8	2	Teak, walnut or white	18·75	3·12
Cantor	20	11 x 4¾ x 18½	8	2	Teak, walnut or white	22·25	3·70
* Available in white at extra charge							
Kelgrove Sales, St. Marks Rise, London E8							
Ste-ma							
Hi-Fi 5	35	10 x 25 x 15	8	4	All teak	52·40	—
350	18	10 x 25 x 15¾	8	3		34·50	—
450	12	9½ x 11½ x 19½	8	2		25·00	—
Keletron							
KN400	8	7 x 6 x 11	8	2	All teak	7·72	Tax inc.
KN600	12	7¼ x 6¼ x 12½	8	3		12·91	Tax inc.
KN800	16	10½ x 8½ x 18½	8	3		15·90	—
KN1100	20	11½ x 9¼ x 21	8	4		20·40	—
KN1600	30	15 x 8½ x 21	8	3		25·20	—
KN2100	40	15 x 11 x 24	8	3		30·60	—
K.F. Products Ltd, Brookfield House, Hopes Carr, Stockport, Cheshire							
PF6–S	4	13½ x 9¼ x 4	8	1	All teak veneer	6·69	1·11
LP6–S	10	13 x 8 x 10	8	1		12·49	2·23
PF8–S	8	15 x 10½ x 5¾	8 & 15	1		8·04	1·34
E138–S	10	18 x 13½ x 9	3, 8, 15	1		13·40	—
KR6	6	8 x 7 x 11	8	1		8·94	1·49
KR8	8	10 x 9 x 17	8	2		15·43	2·57
KR10	10	11½ x 10½ x 21½	8	2		18·86	3·14
KR20	20	15 x 11¼ x 24	8	2		37·75	—
KR25	30	17 x 11 x 28	8	4		59·20	—
Details of p.a. column speakers on request							
Klinger Controls Ltd, 7 Chalcot Road, London NW1 8LU							
S34	6	13 x 7 x 8	8	2	Teak case	9·00	1·50
S35	6	13 x 7 x 8	8	2	Teak or white case	9·00	1·50
S42	12	17½ x 10 x 8	8	3	Teak	16·65	2·70
S50	15	18 x 13 x 7	8	3	Teak	22·65	3·15
S90	25	22 x 13½ x 10	8	3	Teak	32·50	—
LNB Audio Ltd, 25 Cambridge Street, Loughborough, Leics							
Para-Tran-6	10	28 x 20 x 40 cm	8	2	Black front, teak veneer	39·25	Tax inc.
Para-Lab Super	15	23 x 26 x 60 cm	8	3	Black front, teak veneer	59·50	Tax inc.
Para-Lab 20	20	31 x 11 x 11¼	8	3	Teak, black Vynair front	101·50	Tax inc.
H. J. Leak & Co Ltd, Bradford Road, Idle, Bradford 2, Yorks							
Leak 150	18	15¾ x 10 x 8	4–8	2	Teak/walnut	21·28	3·72
Leak 250	18	19¾ x 11 x 10	4–8	2	Teak/walnut	27·66	4·84
Leak 600	40	26 x 15 x 11¾	4–8	3	Teak/walnut	49·50	—
Lecson Audio Ltd, Nuffield Road, Industrial Estate, St. Ives, Huntingdon PE17 4LD							
HL1	50	15 x 17½ x 36	8	4	Various	89·00	—
Peter Lewis Electronics (Brentford) Ltd, Roman House, 281 High Street, Uxbridge, Middx							
LS16	8	11 x 7¾ x 16¼	8	3	Teak	12·50	—
LS15	15	26 x 15⅝ x 12½	8	3	Teak	29·03	—
Lockwood, Lowlands Road, Harrow, Middx							
Major	50	42 x 28 x 17½	8	1	As required	173·00	—
Major	50	41 x 24 x 17½	8	1	As required	180·00	—
Lowther Manufacturing Co, Lowther House, St. Mark's Road, Bromley, Kent							
LIB	15	7½ x 14 x 19	15	1	Teak/walnut/sapele	15·00	1·20
Acousta	20	18 x 14 x 32	15	1	As required	32·00	2·57
Mini-Acousta	20	15 x 13 x 27	15	1	As required	32·00	2·57
Dual Acousta	20	9 x 18 x 32	15	1	As required	32·00	2·57
Audiovector	20	27 x 19 x 34	15	1	As required	70·00	5·61
TPIA & D*	20	32 x 23 x 47	15	1	As required	180·00	—
Auditorium-Acousta	6	9 x 19 x 32	15	2	Teak/walnut	50·00	—
Auditorium-Audiovector	6	27 x 19 x 34	15	2	Teak/walnut		
* Model TPIB, Queen Anne styling, £200							
Metrosound Manufacturing Co Ltd, Audio Works, Cartersfield Road, Waltham Abbey, Essex							
HFS103	10	14 x 9 x 9	8	2	All teak	25·00	4·21
HFS202	20	23 x 11½ x 11	8	2		21·50	—
Duplex 15	15	18¼ x 8½ x 18¼	8	2		36·00	—
Duplex 25	25	16½ x 12 x 27½	8	2		52·00	—
MMG Associates, 19 Southfield Road, Flackwell Heath, High Wycombe, Bucks							
Emperor 101	20	31 x 17 x 9	8	2	Teak Melamine	33·00	—
Keith' Monks Audio Ltd, 26 Reading Road South, Fleet, Hants							
Kmal							
Minor	15	11 x 8¼ x 17½	8 or 15	1	Teak	30·00	—
15/40 Super	15	11 x 8¼ x 17½	8	2	Teak	36·00	—
Hypertone 30/30	30	14 x 9½ x 31	4, 8 or 15	3	Teak	70·00	—
Elf	12	9⅛ x 9¾ x 15⅛	8	2	Various	21·40	3·56
Super Elf	18	11 x 8¼ x 17½	8	2	Teak	28·50	4·74
Elf Major	22	11¾ x 25 x 11¾	8	3	Teak	48·30	8·03
Modaunt-Short Ltd, The Courtyard, Heath Road, Petersfield, Hants							
MS077	20	9½ x 8 x 15¾	8	3	Teak or walnut*	27·50	4·63
MS400	25	15 x 9 x 27	8	3		58·50	—
MS700	30	17 x 12 x 33	8	3		82·50	—
MS235	25	21 x 13 x 9	8	3	Teak/walnut	47·50	8·00
* Other finishes to order.							
B. H. Morris & Co (Radio) Ltd, 84 Nelson Street, Tower Hamlets, London E1							
Sonics							
AS57	10	5⅞ x 8¼ x 15¾	8	1	Walnut	14·80	2·20
Philips Electrical Ltd. Century House, Shaftesbury Avenue. London WC2							
RH411	10	7½ x 10½ x 7½	8	1	Walnut	9·33	1·57
RH412	15	10 x 13¾ x 7½	8	1	Walnut	14·98	2·52
RH402	20	10½ x 10½ x 4¼	4 or 8	2	Walnut	19·12	3·23
RH406	25	13½ x 18 x 9	8	3	Teak	29·09	4·91
RH407	40	16¼ x 21¼ x 8¾	8	3	Teak	45·36	7·64
RH405	30	13½ x 18 x 9	8	3	Walnut	35·00	Tax inc.

Model	Power rating (W)	Size (in)	Imped-ance (Ω)	Drive units	Finish	Price	P. Tax
Radford Acoustics Ltd, Bristol BS3 2HZ							
Tri Star 90/50	50	12 x 9 x 21	8–16	3	Teak/walnut/white	45·00	—
Monitor 180/50	50	13½ x 10½ x 30	8–16	3	Teak/walnut/white	72·50	—
Studio 270/50	50	17½ x 12½ x 38	8–16	3	Teak/walnut/white	100·00	—
Studio 360/100	100	18¾ x 15 x 45	8–16	10	Teak/walnut/white	147·50	—
Radio & Electronic Distribution Co, 55 Goswell Road, London EC1							
D131E	20	6 x 8¾ x 10	8	1		15·00	Tax inc.
D132E	20	6 x 8¾ x 10	8	2		19·45	Tax inc.
DP202E	20	9 x 9½ x 15½	8	2		24·65	Tax inc.
DF202E	20	5½ x 13 x 21	8	2		25·80	Tax inc.
D252E	25	12½ x 14 x 24	8	2		44·90	Tax inc.
D253E	25	12½ x 14 x 24	8	4		51·30	Tax inc.
Radon Industrial Electronics Co Ltd, Brooklands Trading Estate, Orme Road, Worthing, Sussex							
SC1	10	19 x 10 x 6	8	2	Teak	13·88	2·40
SC2	12	24½ x 12¼ x 7	8	2	Teak	18·88	2·88
SC3	15	23 x 12 x 11	8	2	Teak	24·00	—
SC4	25	30 x 16 x 9	8	5	Teak	34·00	—
* Varies with finish							
Rank Bush Murphy Ltd, Power Road, London W4							
Bush Arena Hi-Fi							
L510	15	14 x 9½ x 7¾	4	3	Teak	39·73	—
L520	15	17 x 11 x 9½	3·2	3	Teak/rosewood	53·75	—
L530	25	22¾ x 16 x 9½	4	3	Teak	91·14	—
Rank Wharfedale Ltd, Bradford Road, Idle, Bradford, Yorks							
Wharfedale							
Denton 2	18	14 x 9¾ x 8¾	4–8	2	All teak/walnut	35·75*	6·25
Linton 2	20	19 x 10 x 9½	4–8	2		44·26*	7·74
Triton 3	25	21¾ x 9¾ x 9	4–8	3		55·32*	9·68
Melton 2	30	21 x 14½ x 10	4–8	2		35·00	—
Dovedale 3	30	24 x 14 x 12	4–8	3		47·50	—
Rosedale	45	23½ x 23 x 13½	4–8	2		69·00	—
* Per pair							
Rogers Developments (Electronics) Ltd, 4 Barmeston Road, London SE6 3BN							
Wafer	12	16⅝ x 2½ x 13⅛	15	2	Afromosia	20·00	3·41
Ravensbrook	20	19 x 13 x 7¾	8	2	Teak	47·50	8·10
Rogers B.B.C. Studio monitor	25	12 x 12 x 37	15*	2	Teak	83·50	12·81
* Other values to order							
Rola Celestion Ltd, Ditton Works, Foxhall Road, Ipswich, Suffolk, IP3 8JP							
County	25	19 x 10 x 9½	4–8	2	All teak/walnut	20·97	3·53
Ditton 101	20	12¾ x 8¼ x 6¾	4–8	2		20·40	3·43
Ditton 120	20	17¼ x 9 x 7¾	4–8	2		24·00	4·04
Ditton 15	30	21 x 9½ x 9¼	4–8	2		32·00	5·38
Ditton 44	44	30 x 14½ x 10	4–8	2		54·00	—
Ditton 25	60	32 x 14 x 11	4–8	3		65·00	—
Ditton 66	80	40 x 15 x 11½	4–8	3		99·00	—
Sheppard Audio Ltd, 275 Watling Street, Radlett, Herts							
Chesham de Luxe	15	18 x 11¼ x 7¼	8	2	All teak*	31·00	—
Chesham Super	15	18 x 12 x 9	8	2		32·50	—
Aldenham de Luxe	25	23¼ x 15 x 10¼	8	3		55·00	—
Elite Super Mini	30	24 x 14 x 12	8	4		85·00	—
* Also in walnut or mahogany							
Shriro (U.K.) Ltd, 42 Russell Square, London WC1							
Pioneer							
CS53	40	16½ x 12 x 22½	8	2	All walnut	44·25	—
CS66	40	12 x 11½ x 22	8	3		55·67	8·04
CSE700	60	15 x 11¾ x 26	8	3		84·40	—
CSE500	50	13 x 11¾ x 22	8	3		61·35	8·86
CSO5	40	14¼ x 20	8	4		65·36	9·48
CSE200	20	6 x 6 x 9	8	1		19·30	2·79
CSE900	75	16 x 11 x 27	8	3		127·28	—
J. J. Silber Ltd, 11 Northburgh St, London EC1							
Silver							
SX44	20	10 x 15½ x 7	8	2	All walnut	23·04*	3·88
SX66	25	11¼ x 17¾ x 8	8	2		41·74*	7·04
SX88	45	14¾ x 25⅜ x 12	8	3		101·45*	17·11
* Per pair							
Sinclair Radionics Ltd, London Road, St. Ives, Huntingdonshire, PE17 4HJ							
Q16	14	10½ x 4 x 10½	8	1	Teak	8·98	1·76
Q30	25	23½ x 34½ x 2½			Teak surround		—
System 2000	14	8½ x 4 x 10½	8	1	Aluminium	12·60	2·48
Sonab Ltd, 136 Mansfield Road, London W3							
V-1	35	12 x 12 x 12¼	8	1	Various	34·12	5·38
OA-4	35	11½ x 17 x 17½	8	2	Various	47·90	7·60
OA-5	40	9½x 17 x 24	8	2	Various	58·24	9·27
OA-6	50	9½ x 17 x 27	8	3	Various	141·17	22·33
Sony (U.K.) Ltd, Ascot Road, Bedfont, Middx							
SS3000	15	28½ x 15¾ x 11½	8	3	Walnut	63·00	—
SS7000	25	26¾ x 15½ x 32½	8	3	Walnut or white	159·50	—
SS1005	15	18 x 9 x 7	8	2		29·74	5·01
SS3005	15	9 x 6½ x 5½	8	2		14·34	2·41
T.A.K. Continental Importers, 16a High Street, Stone, Staffs							
LB66	30	4½ x 12 x 24	4·5	3	Various colours	59·50	9·50
Tannoy Products Ltd, Norwood Road, London SE27 9AB							
IIILZ Mk. II	25	15 x 9¾ x 21	8	1	Teak or mahogany	41·00	—
Lancaster 12	25	25 x 12½ x 32½	8	1	Teak or mahogany	63·00	—
Lancaster 15	30	25 x 12½ x 32½	8	1	Teak or mahogany	69·00	—
York	30	23½ x 14½ x 43	8	1	Walnut or mahogany	86·00	—
G.R.F.	50	40 x 26½ x 46	8	1	Teak or mahogany	140·00	
Autograph	50	43 x 26½ x 58½	8	1	Teak or mahogany	195·00	—
Chatsworth	30	33¼ x 15½ x 10½	8	1	Teak	57·00	—
Wilkinson/Form Electronics, Low Quay, Blyth, Northumberland							
WF25	12½	17 x 10 x 9	8	2	Both teak		—
WF40	25	22 x 12 x 10	8	2			—
Worden Audio Developments Ltd, 54 Chepstow Road, London W2							
A	30	53 x 17 x 24	15	1		85·00	—
B	30	47 x 22 x 16½	15	1		75·00	—
C	30	27 x 24 x 17	15	1		65·00	—
D	15	16 x 9 x 9½	8	1		29·50	Tax inc.
Woollett Audiostatics, 21 Anerley Station Road, London SE20							
Claremont	20	10 x 8¼ x 8½	16	1	Various	24·90	—
Leven	20	11½ x 8¾ x 8	16	1	Various	24·90	—
Frensham Bass	20	24¼ x 14 x 31	16	1	Various	46·00	—
Kelsey Bass	20	18 x 14 x 34	16	1	Various	46·00	—
Grasmere, Futura	20	18 x 14 x 34	16	2	White, teak and black	63.75	—
Grasmere, Moderna	20	18 x 14 x 34	16	2	Teak, black	61·75	—
Esdiyn	20	18 x 14 x 31	16	2	Unfinished	48·00	—
Como Futura	16	15 x 12 x 20	16	2	Teak	34·75	—
Como Moderna	16	15 x 12 x 20	16	2	Teak and black	32·75	—
Wye Electronics Ltd, Queen Street North, Whittington Moor, Chesterfield, Derbyshire							
525	10	12 x 8½ x 19¾	4	2	Teak	19·58	—
1300	15	15 x 7½ x 36	4-18-16	2	Teak	37·80	—
Vernitron Ltd, Thornhill, Southampton SO9 5QF							
Sansui							
SP1700	70	16 x 10⅞ x 25¼	8	3	Walnut	91·07	—
SP2500	80	16¾ x 10⅞ x 25	8	3	Walnut	100·75	—
SP3500	100	17¾ x 11 x 25	8	4	Walnut	121·90	—
SP3005	60	25 x 17 x 27¾	8	4	Walnut	167·74	—
SF2	65pk	15¾ x 24¾ x 15¾	8	3		99·45	16·58