

# Wireless World

ELECTRONICS, RADIO, TELEVISION

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# A NEW JUNGLE VALVE

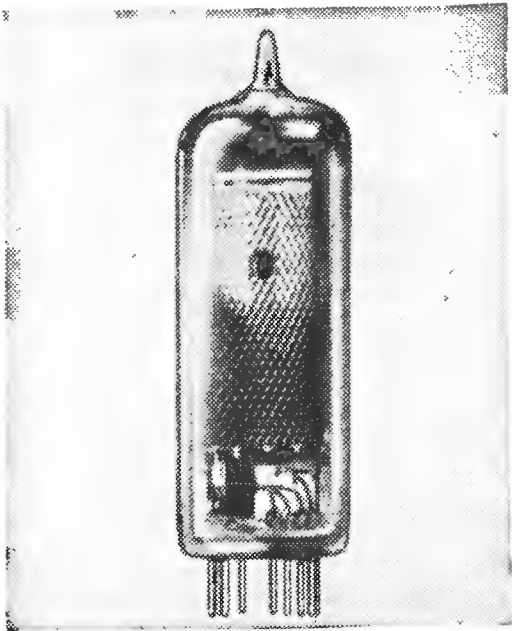
## ECH84

### FOR DUAL-STANDARD TV RECEIVERS

**T**HE Mullard triode-heptode, type ECH84, is now appearing in the "jungle" stages of dual-standard television receivers in this country. The valve has already been widely adopted by manufacturers producing receivers for 625-line transmission systems using negative vision modulation.

The heptode is generally operated as an interference-cancelling sync pulse separator, and the triode section as a pulse limiter. The heptode function is particularly valuable when interference pulses which are in the same sense as the sync pulses, occur in the video waveform and tend to disrupt synchronisation.

The ECH84 has been designed specifically to supersede the ECH81 in the sync separator application. It is tested during production under conditions likely to be encountered by it in television receivers, so that good operation at low voltages is ensured. Another consequence of this specific design is that the linearity of the control grid characteristics of the heptode section is markedly better than that of the earlier valves. In the triode section, too, higher values of mutual conductance and amplification factor have been achieved. These improved properties of the ECH84 are reflected by better receiver performance under fringe reception conditions.



## AW21-11, 8½ INCH TUBE FOR PORTABLE TELEVISION RECEIVERS

COMPACTNESS and low battery consumption in a portable transistor television receiver are made possible with the Mullard AW21-11 tube by virtue of its 8½ inch screen diagonal and 90 degree deflection angle. A car battery can be used as the power supply because the heater voltage of the tube is 11.5V. The power consumption of the heater is only 0.7W.

The new shortened unipoten-

tial gun retains the excellent flat focusing characteristics of unipotential guns, and also contributes to compactness. The drive requirements of the gun are compatible with the performance of present-day video output transistors without the need to shorten the grid base. A gun with a high e.h.t. rating and exceptional insulation properties is chosen to lessen the likelihood of flashover occurring.

## MULLARD TRANSISTOR FOR TV TUNERS

### *Alloy- Diffusion Type AF102*

**T**HE AF102 is the first Mullard transistor designed specifically for use in television tuners. It is made by the alloy-diffusion technique, which has enabled an extremely thin base (of the order of one ten-thousandth of an inch) to be produced, and hence a very low base impedance to be achieved. The alloy-diffusion technique has also produced an extremely low feedback capacitance. Opera-

## WHAT'S NEW IN THE NEW SETS

These articles describe the latest Mullard developments for entertainment equipment

tion up to frequencies of 260Mc/s is thus possible with the AF102.

The outstanding features of this transistor are the high gain at very high frequencies—more than 10dB in Channel 13 in a typical r.f. amplifier stage—and the extremely low noise figure at these frequencies, typically 6dB at 200Mc/s. This performance readily explains why the AF102 is now to be found in the r.f. amplifier, mixer and oscillator stages of the first transistor television receivers.

MVE 1010

## *Retirement of Hugh Pocock*

WE know that many of our readers, and particularly those who have been with us since the days before broadcasting began, will wish to join with us in wishing Hugh Pocock a continuation of good health and the enjoyment of many years of well-earned retirement.

It was in February, 1913, that he joined the publications department of the Marconi Company and was asked to assist in the production of the first issue of *The Wireless World*, under which title *The Marconigraph*, hitherto virtually a house journal, signified the acceptance of its wider responsibility as the world's first radio journal.

On the outbreak of war in 1914 his technical knowledge (he held a G.P.O. experimenter's licence before joining Marconi's) qualified him for a commission in the Royal Engineers in which he saw service in the U.K., Egypt, Mesopotamia and Persia where, with the rank of Captain, G.H.Q. Staff, Baghdad, he was mentioned in dispatches.

The quality of his early work on *Wireless World* and in editing *The Yearbook of Wireless Telegraphy and Telephony* had evidently left a lasting impression at Marconi's, for in 1920 after demobilization he was offered and accepted the editorship of *Wireless World*. During the war the journal had subsisted mainly on such items of news as were released by the censor or could be gleaned from our correspondents in America, but now the fruits of intensive wartime technical development were becoming available to the civilian, both professional and amateur. They turned to *Wireless World* for information and guidance and under H.S.P.'s percipient direction it gave them the facts they were looking for. Not only that, but it helped to secure for the amateur the greater freedom to experiment which authority seemed reluctant to restore.

It was about this time that the human voice was heard, almost incredibly, among the spark and c.w. morse messages which had hitherto seemed sufficient reward for the successful construction of a wireless receiver. The Melba concert from Chelmsford, the Croydon aerodrome radiotelephone transmitter, the Dutch concerts from the Hague, the Marconi experimental broadcasts from Writtle, led in rapid succession to the start of national broadcasting in 1922. Without neglecting the interests of his professional readers H.S.P. reinforced and reoriented the resources of his staff to meet the flood of requests for

constructional articles on broadcast receivers, and in the ensuing years increased the influence and authority of the journal by his shrewd and outspoken comment on matters of policy relating to broadcasting and to the radio industry in general.

His capacity was soon recognized by Iliffe's when our journal was acquired by them in 1924, and by 1936, in addition to editing *Wireless Engineer* (formerly *Experimental Wireless* and now *Industrial Electronics*), he was asked to take over the managing editorship of *Electrical Review*. In 1948 he was appointed to the board of Iliffe & Sons and was in addition responsible for the direction of many other journals with as divergent interests as *Iron & Steel*, *British Plastics* and *Architect and Building News*—to mention only a few.

But we liked to think, indeed we knew, that he always retained a rather special interest in his first journal, that his advice could be and always was sought in any problem above the level of the day-to-day running of the journal. His calm and unruffled manner is the exterior manifestation not only of an innate courtesy but of an outstanding ability to appreciate and resolve the root cause of a problem, either material or human in origin.

When in 1959, for the third time in our history, the ownership of the journal changed hands he stayed, although then past the normal age of retirement, to see us settled after the new regrouping of companies, his only concession to the calendar being to relinquish the control of some of his many journals in order the better to concentrate on those covering radio, electronic and electrical interests. He retires as Chairman of Iliffe Electrical Publications Ltd. and a member of the board of Associated Iliffe Press a few days after this issue appears, on 31st December, 1962—49 years and 10 months after joining *Wireless World* as an editorial assistant.

He has for many years been a Member of the Institution of Electrical Engineers and is also a Life Senior Member of the Institute of Electrical and Electronic Engineers (formerly I.R.E.).

In wishing godspeed to H. S. Pocock we would also like to take this opportunity of welcoming W. E. Miller who is now Managing Director of our Company. As a past-President of the British Institution of Radio Engineers and for many years Editor of *Wireless and Electrical Trader* he is no stranger to our way of life.

F. L. D.

# THE SIMOFOON

A NEW SERVICE OF THE DUTCH PTT

By Ir. G. M. UITERMARK\*

*In our issue for October 1961 we gave, in the report of the Amsterdam Radio Show (Firato), brief details of a selective calling system of unusual interest which was then under development by the Dutch Post Office.*

*This fuller description of the development of the system is based on an article which appeared in the Dutch journal "De Ingenieur," Vol. 73, No. 52, Dec. 29th, 1961.*

**A**BOUT March 1961 the Management Council of the Dutch Postal, Telegraphic and Telephone Service took the decision to introduce the Simofoon system as a national PTT service. Commissioning of the service was fixed for the second half of 1963, but in fact a pilot service with 50 representative subscribers is due to start at noon on 7th January.

The origin of the line of thought which led to the birth of the Simofoon system dates back to the time when the National Mobilofoon (radio telephone) network switched over from a two-channel to an eight-channel system. That was in 1955.

In Fig. 1 circular symbols show the original network as it operated from 1949 to 1955. As already stated, it worked on two frequencies. These frequencies therefore recurred necessarily in places which were not very far from each other, so that The Hague and Utrecht, for instance, had base stations which operated on the same frequency. This limitation of the number of channels raised a number of difficulties. For instance, if a mobile subscriber wished to make a call from the vicinity of Gouda, the outgoing call was picked up by the telephone operators at both The Hague and Utrecht. If he asked to be connected to a number in the national telephone network, the call might be set up by, say, the operator at Utrecht. When the call was ended, it might frequently be offered again, this time by The Hague, the operator there having found the number engaged at first, but after repeated attempts managing finally to get through!

Apart from this drawback, there was the difficulty that the number of basic stations could not be increased to give satisfactory coverage of the entire country. This would have meant an excessive increase of mutual interference. Consequently, there were a number of blank areas clamouring to be filled up as Mobilofoon traffic rapidly increased. Moreover, the traffic capacity of the two available channels was too small.

In 1955 the two-channel network was replaced by one with eight channels (Nos. 2-9), the stations being indicated by squares in Fig. 1, with the channel numbers in brackets.

The number of base stations was considerably increased. The confused situation at places between

The Hague and Utrecht disappeared, for The Hague now operated on channel 5 and Utrecht on channel 3. The other base stations that work on channel 5 or 3 are so far from these two towns that their calls cannot interfere with The Hague or Utrecht. In addition, traffic capacity has been greatly increased. Driving in the neighbourhood of Zwolle, a Mobilofoon subscriber can make a call via Emmeloord, Harderwijk, Dedemsvaart or Deventer, if channel 2 (Zwolle) is found to be engaged. For everyone wishing to initiate calls from their car or ship the new 8-channel network meant a great improvement. It was the reverse for those who tried to contact a Mobilofoon subscriber from an ordinary telephone. It was, of course, necessary to know approximately—even with the old 2-channel network—where the mobile subscriber was, but under the old system only two base stations in his vicinity needed to transmit a call to ensure that it was received by the mobile instrument. With the 8-channel system a similar calling procedure is practically impossible, so that in this respect the new Mobilofoon network is definitely inferior to the old one.

When plans for the new 8-channel network were being studied this problem of calling the mobile subscriber was recognised at an early stage. We had a choice of two solutions, namely (1) a compromise whereby more than two but fewer than eight channels would be used, and (2) a new system, still to be devised, which would enable mobile subscribers to be called but would be independent of the Mobilofoon system. The first solution would have meant that calls from cars or ships suffered a loss of reliability, and this we felt to be unacceptable. The 8-channel plan was adopted, but the list of problems still to be solved included that of devising a new system which would allow mobile subscribers in the Netherlands to be located quickly and reliably.

A system of this kind is basically classifiable under the term "selective calling," but since it was clear to us that existing systems would not satisfy our requirement, we started thinking up names for the brain-child that was still to be born. From over 100 suggestions the name SIMOFOON was chosen for the new service. The word is intended to denote: a service which SIGNALS that a MOBILE subscriber is wanted on the MobiloFOON or tele-

\*Head of the Central Wire Broadcasting and Mobile Radio Department of the Dutch PTT

phone. The word Simofoon satisfies the standards of intelligibility observed in telephony or radio telephony, and is suitable for international acceptance, like the term Mobilofoon coined in Holland.

The first step on the long development path that the Simofoon had to cover was taken early in 1956 in reply to a request from the Local Telephone Service at The Hague. It was desired to fit various service vehicles, used for different purposes such as the maintenance of public clocks, with facilities for selective calling by radio. Only calling facilities were needed, as subsequent conversation was to take place by telephone or Mobilofoon.

This request fitted in perfectly with our development plans. Even at this early moment it was clear to us that the Simofoon should *not* be built into the Mobilofoon set, although this combination is certainly used abroad. It makes the Mobilofoon equipment unnecessarily expensive and prevents use of the Simofoon by that section of the public who wish to be called up but are quite content to conduct the ensuing conversation over the nearest telephone (e.g., doctors on their rounds).

For the network required by the Local Telephone Service the equipment chosen was a modified version of the "Autoruf" which had already been marketed by Haslar A. G., Berne. This set received signals from an a.m. transmitter which was modulated by tone generators and could be operated by means of a telephone-type dial. Selection in the receiver was effected by mechanical relays which resonated at a particular audio frequency. The modification consisted in the addition of a relay, a thermal relay and a red lamp. When a call was first emitted, it caused a white lamp to light up. When it was repeated within two minutes, a red lamp lighted. This indicated that the call was of an urgent nature. A "white" call meant that the called party could take his time about finding a telephone box or café from which to ring back his home or office.

When the network for the Local Telephone Service was set up at The Hague, it provided a welcome opportunity to connect a few "guinea pigs" to it. The most important points were to conduct market analysis and to find out what needs existed among the public and to what extent these could be met. We therefore approached several people who were representative of professions which we thought would be interested in a Simofoon service. As a result,

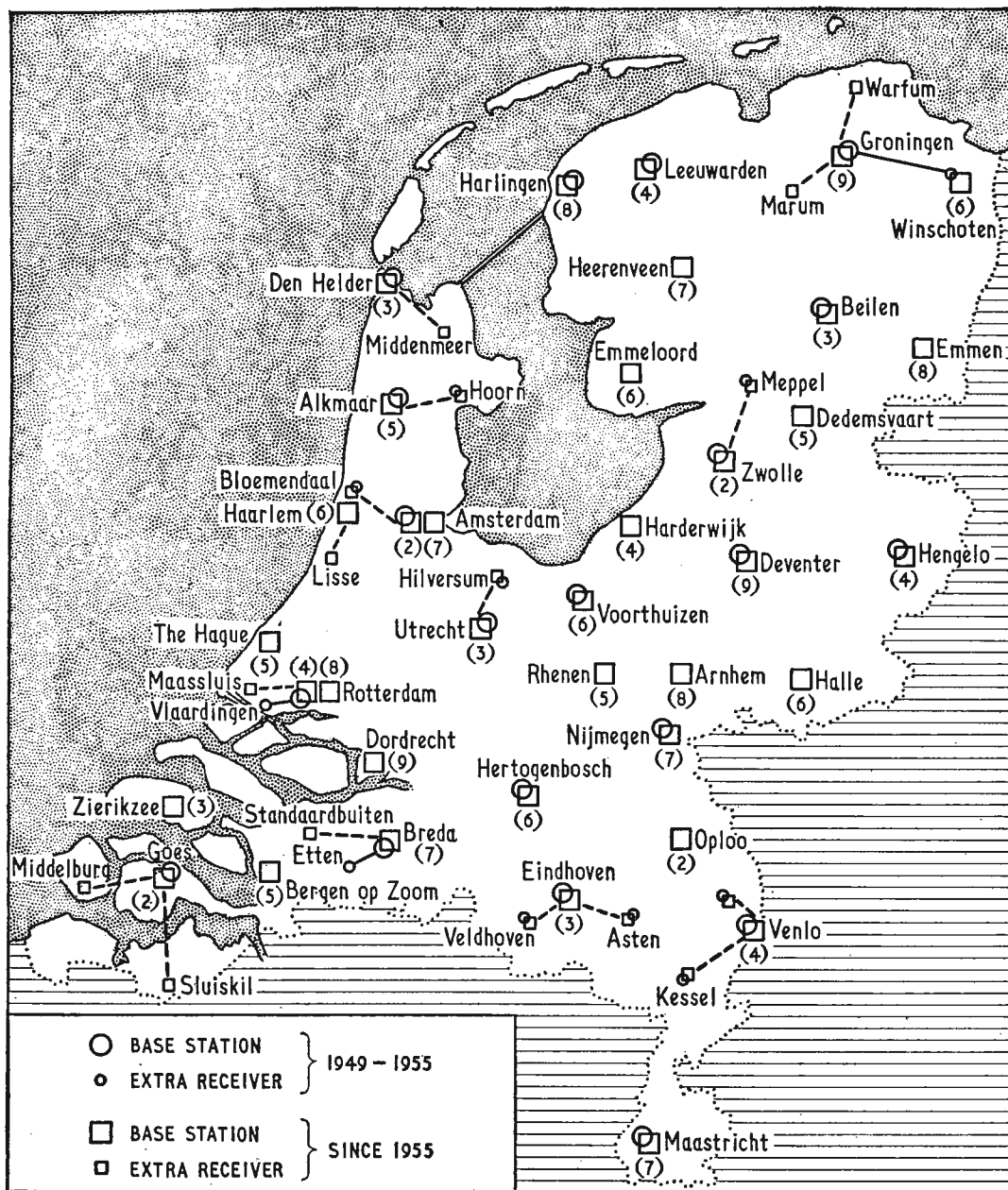


Fig. 1. Base stations in the Netherlands Mobilofoon network 1949-55 (circles) and since 1955 (squares). Channel numbers are indicated in brackets.

a veterinary surgeon, a general practitioner, a firm of carriers, a TV service vehicle and members of various other trades or professions were connected to the network.

Several years' experience has demonstrated a remarkable, yet extremely important fact: the lease of Simofoons to firms and private individuals is bound to have a snowball effect on "sales." In fact, however, this discovery is less remarkable than it appears to be at first glance. The snowball effect starts when it has been demonstrated that the set gives savings in time and money that not only exceed the rental many times over, but also produce a considerable decrease in business expenses. An example will help to make this clear. If a carrier's van travels with half a load from Groningen to Amsterdam and the office receives a telephone call from a customer in Zwolle who also has half a load of goods to be taken to Amsterdam, hundreds of kilometres and much overtime can be saved if the driver is notified in time. To remain competitive other firms will be forced to make the same savings. For the same reason it could also be foreseen that introduction of the five-day week would produce a snowball effect.

From the many facts we were able to learn from

experimental operation at The Hague, the following conclusion was—for the reason stated above—the most important we could formulate: *very many subscribers can be expected.* The number of subscribers to the national Mobilfofon network can be expected to multiply within a short time. For the network this means that *a large number capacity and more particularly a large traffic capacity are needed.* The radio path, however, is not the ideal medium for obtaining large traffic capacity, especially if we are determined to stick to receivers with single-channel reception. We have, however, to insist on the latter condition if we wish to protect the public against wrong positioning of a channel selector, which would render the equipment useless. The only effective protection is to drop the selector, which compels us to use a single-channel network.

As our thoughts travel along these lines, the requirements the system under design has to meet gradually take definite shape. We have already seen that the system has to be a single-channel one and have a large number and traffic capacity. But a number of other requirements make themselves felt. Is there, for instance, much point in calling up a doctor to ask him to rush to the scene of a street accident if he only spends a minute or so in his car between visits lasting 10 or 15 minutes to his patients? The least that is necessary is that the Simofofon in his car should keep an incoming call in force until the doctor gets into his car again. Then he can note the call and reset his Simofofon for a

subsequent call. This is not very satisfactory for the victim of the accident. More immediate warning to the doctor would be much more to the point. Consequently, we have to lay down the requirement that we do not call up his car but the person himself. In other words, the receiver must be portable, so that the driver can take it with him when he leaves the car. This requirement in turn gives rise to several others, namely (1) upon receipt of a call an acoustic signal must be generated for several seconds, and (2) when the set is used indoors, or outdoors in closely built-up areas, it must be possible to check whether the field strength is sufficiently great to guarantee reliable reception of signals. Of course, when in the car, the set must be powered from the car battery, with automatic switchover to built-in batteries when the subscriber leaves his car.

Battery supply demands a fully transistorized receiver. Although all the transistors needed for a fully phase-modulated receiver with high sensitivity had not yet appeared on the market in 1955, we took a chance and started development work on the tubeless receiver in co-operation with N.V. Philips Telecommunicatie Industrie of Huizen, in the hope that the new transistor types would be developed sufficiently quick. This hope was fulfilled and there was no delay in development.

In addition to deciding the requirements to be met by the receiver and how it was to be developed, the method of operating the service had also to be studied closely.

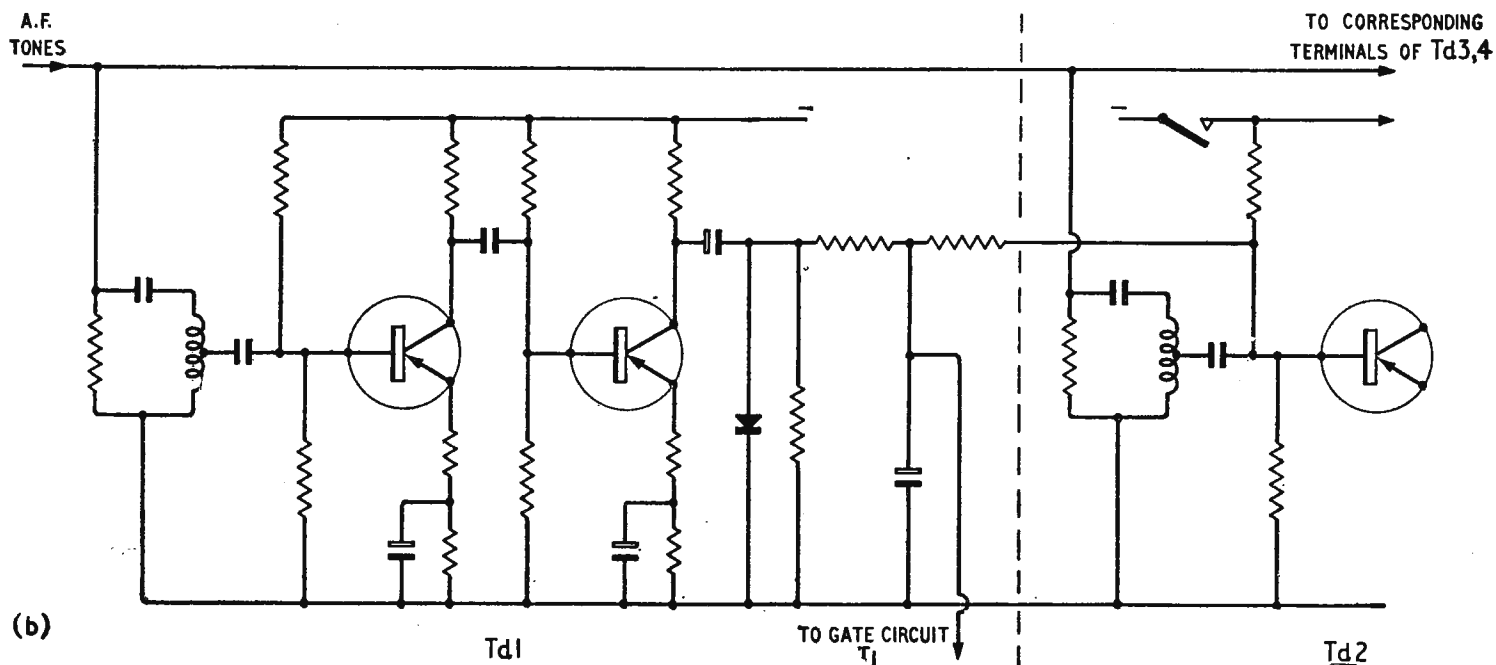
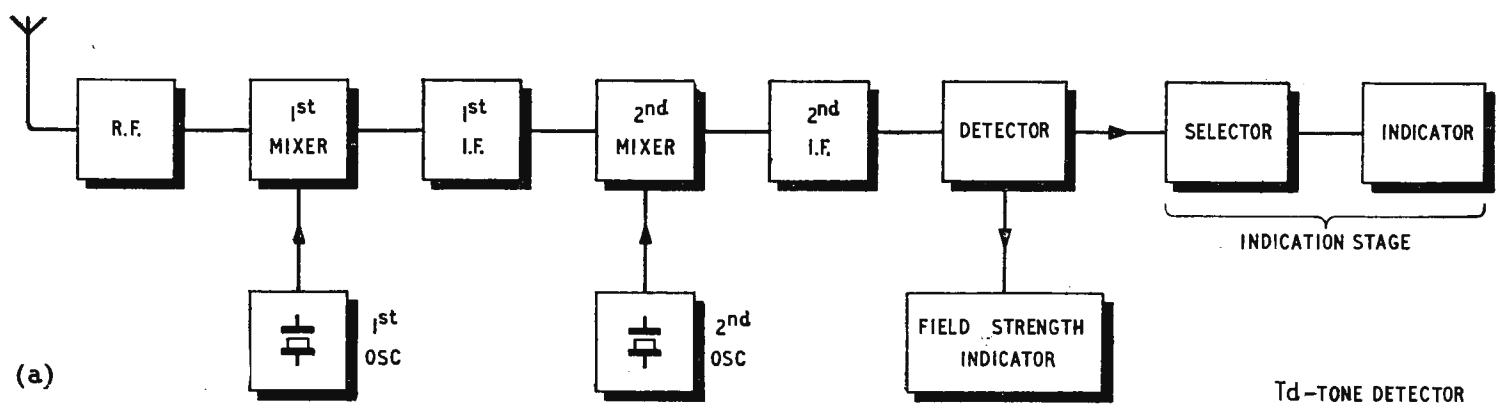


Fig. 2. (a) Block diagram of Simofofon receiver and (b) circuit of a tone detector.

In the Hague experimental network control was in the hands of a telephone operator. The person making the call rang this operator and gave her his telephone number. The operator noted the number of the Simofoon subscriber, whereupon the calling party replaced his receiver. The operator then dialled the Simofoon subscriber. As soon as the latter answered, she told him the caller's town and telephone number. Then the Simofoon user would call that number personally.

A system of this sort is conceivable in a small local network, but if the whole of Holland is to be accessible via a single central point and it is certain that many thousands of people will subscribe to the service, it will immediately be obvious that manual operation cannot cope with the situation.

The time taken to note the caller's telephone number, to dial the Simofoon number to the transmitter, to await a reply and then to pass on information would be so long relatively that the transmitter would only be used to a fraction of its maximum capacity.

From what has been said it must be concluded that manual operation is not practicable for the Simofoon service and that the only solution is complete automation. Full-scale automation means that the calling telephone subscriber must make himself known to the Simofoon subscriber by dialling. The only means he has at his disposal for doing this is his rotary dial, so that he must use it to give more information to the transmitter than merely the Simofoon subscriber's number. One problem that now arises is that we cannot dial unlimited series of digits into the telephone network (the limit is five digits after the second dialling tone if more than three digits have been dialled before it). Another is that the Simofoon receiver now has to provide more information than the mere fact that there is a call for the Simofoon subscriber.

By adopting a fairly simple arrangement, this last requirement has been successfully satisfied and it is now possible to design the receiver so as to display any of six code digits. This has enabled us to eliminate the need to apply to a telephone operator for information. An example will help to make this clear. Before setting off on his journey, the Simofoon subscriber can arrange that if he is called up from his home the code digit 1 will be dialled and that if the call comes from his office, code digit 2 will be used. This still leaves 4 code digits to spare and he can decide for himself how these are to be used. He may, for instance, arrange with a business associate that if the latter needs to contact him on a particular day he will call him by dialling code digit 3. Digit 4 on that day might be allocated to a message the subscriber was expecting, that an appointment has been cancelled, so that he would not need to return home early.

From this it will be clear that a directory of Simofoon subscribers would be pointless, as strangers can only call up via a subscriber's office or home. This is only logical, for strangers cannot know

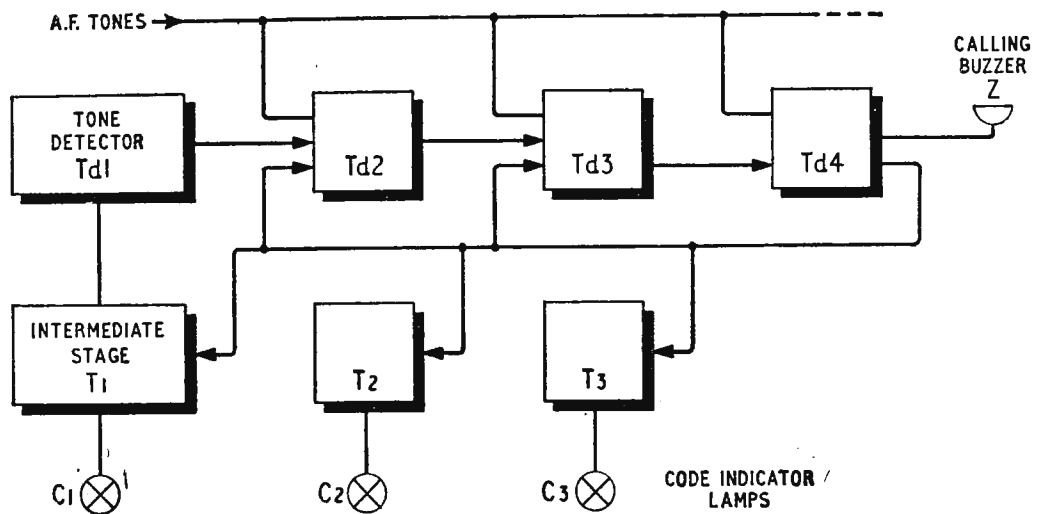


Fig. 3. Block diagram of indicator section.

whether the subscriber is at home, at his office or away on business at a particular moment.

All the requirements resulting from what has been said above have been satisfied in the Simofoon receiver as actually designed and produced. Fig. 2 shows a block diagram of the receiver and the circuit diagram of a tone detector.

As will be seen from the block diagram, the Simofoon is a genuine phase-modulated receiver and its sensitivity and stability are particularly high. The field-strength indication is taken from the detector. If a lamp lights up when a button is pressed, the local field strength is sufficient for good reception.

Selection, and extension of the code, are effected with the aid of tone detectors. The transmitter successively emits four a.f. tones, three of which are used for selection, while the fourth is always of the same pitch. A tone detector consists of a high-quality LC circuit which, if tuned to the received tone, applies—after rectification—sufficient voltage to a 2-stage transistor amplifier to charge a capacitor. This voltage creates access to the next detector. If the three detectors accord with the transmitted signal, the "distinguishing" tone (radiated by the transmitter) is received. This tone energizes the fourth tone detector which now connects the other three in parallel and gives access to gates T1, T2 and T3 (see Fig. 3). For the purpose of the code message the transmitter now repeats one or more of the tones previously used for selection, causing one or a combination of lamps C1, C2 and C3 to light up. From this it is a simple matter to read the coded digit.

The distinguishing tone referred to above has a second important task to perform. It provides a.f. protection for the r.f. receiver. Because of the small number of channels available in the 80-Mc/s band, it will be necessary some time in the future to operate a number of local networks (to which we will, of course, eventually give due thought) on the same wavelength. If, for example, a local network at Haarlem and another at The Hague go into operation on the same wavelength, a Sassenheim subscriber to The Hague network may receive on his set a correct tone combination sent out by the Haarlem transmitter but intended for a Haarlem subscriber. Spurious calls can nevertheless be avoided by having different distinguishing tones for the Haarlem and Hague networks. The same principle would apply if a similar system was used in adjacent countries and, as might happen in certain

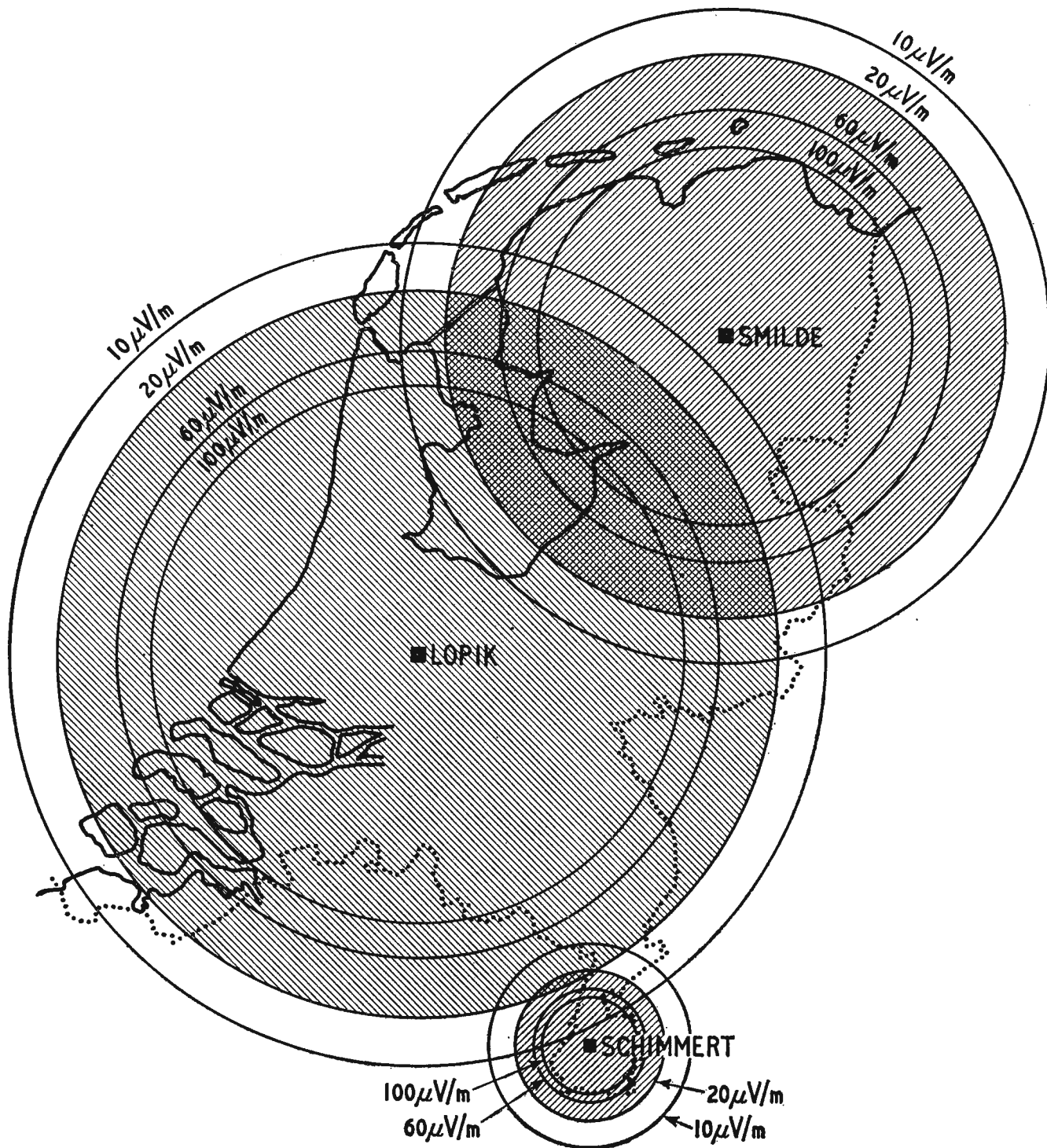


Fig. 4. Transmitter coverage for the Simofoon network.

conditions favourable to propagation, signals from those countries could be picked up by Dutch receivers.

In choosing the tone system, the decisive factors are number capacity and traffic capacity. The number of tones to be given in succession must be as small as possible because tone detectors are expensive and add to the weight. The following table

No. of tones used	No. of tone frequencies	No. of subscribers
4	10	7,300
4	12	15,800
4	15	41,000
4	20	130,000
3	20	7,200
3	25	14,500
3	30	25,230

shows the number capacity (i.e., the number of subscribers) that can be achieved when 4 or 3 of a larger number of possible tones are used.

Allowance has been made in this table for the omission of numbers in which two or more successive tones would have the same frequency. Tone detection is consequently simpler.

We have chosen the 3-out-of-30-tones system, which fixes the capacity at 25,230 subscribers. A small proportion of the possible numbers will be omitted because they do not permit the use of all code digits. As we shall see later, the above capacity is doubled by means of a simple device, so that approximately 50,000 subscribers can be connected to the national network. This number seems large enough to raise doubts about the traffic capacity.

On the basis of technical considerations it can be reliably stated that the minimum time needed per call is 0.7 sec. As the call has to be repeated again 15 seconds later, the time required for a complete call to a subscriber is 1.4 sec. The purpose of



repetition is to increase reliability, for if a car happened to be under a railway viaduct at the exact moment of a call intended for it, the call would be lost unless repeated.

If we assume that 10% of the calls made in any one day occur in the busiest hour, then  $10 \times 3600 \times 1.4 = 25,700$  calls per day must be possible. That means 0.5 of a call per subscriber per day! A similar figure was found from our observations in the experimental network. American literature on the subject also gives an average of 0.5 sec. calling time per subscriber. Thus we see that despite the extremely short duration of a call the traffic capacity would barely be sufficient if the full number capacity were utilized.

The calculation above is based on the assumption that the whole of Holland could be covered with a single transmitter. This, in fact, is not the case (Fig. 4).

If we were to erect the Simofoon transmitting aerials on the top of the TV mast (375m. or 1,240 ft.) at Lopik we should obtain with an e.r.p. of 10.8 kW the field strength diagram shown in the figures. The receiver sensitivity is fixed at  $0.5 \mu\text{V/m}$  so that the  $10 \mu\text{V/m}$  circle can be taken as marking the usable range, at least in country districts. This means that the province of Zeeland Flanders is covered but parts of Friesland, Groningen, Drenthe, Twente and Limburg are not. Ample provision can be made for these unserved areas by erecting a transmitter of 1.5 kW e.r.p. with an aerial height of 285 m. (940 ft.) at Smilde and a small transmitter (about 50W) at Schimmert.

But now we have a serious problem on our hands. Although the Smilde and Schimmert transmitters can operate simultaneously on the same wavelength because their effective ranges do not overlap, such is not the case in relation to Lopik. This would mean that the Simofoon receiver would have to possess switching facilities which the subscriber would have to use on leaving the territory covered by Lopik and entering that covered by Smilde. On behalf of our future clients, many of whom would undoubtedly forget to do so, we dismissed this arrangement as unacceptable.

The most obvious solution was the following: Lopik transmits a call with a duration of 0.7 sec. Then the transmitter is switched off and both regional transmitters go on the air with the same call. Then Lopik comes back with a new call, and so on. The traffic capacity, which was already meagre

enough, would consequently have been halved. As this was considered unacceptable, another solution had to be sought.

This was found, not by having the transmitters switch on and off (against which there are also technical objections), but by having them switch alternately from an A channel to a B channel, with a spacing of 50 kc/s between the two. In this way, the halved traffic capacity is doubled again, as also is the number capacity. As we based our calculation on this doubling, the value shown in it remains valid.

The over-all procedure thus obtained is that shown in Fig. 5. The main transmitter broadcasts call 1 on the A channel, then call 3 on the B channel, followed by call 2 on the A channel. The auxiliary transmitters do the same with a time lag of 0.7 sec. Fifteen seconds later the procedure is repeated. The receivers therefore do not have to be switched over, but they have to be available in two versions, viz. an A version and a B version. The subscriber is not informed what version is issued to him. If he has an A type, he must not be surprised to come across his own number on another set. That other set will be a B type.

Our first shaky steps on the experimental path were not very hopeful ones. Using a transmitter which automatically and continuously repeated several coded calls, we found the line along which the field strength was  $2 \mu\text{V}$ . The transmitter was sited on the TV tower at Roosendaal. The line we wanted proved to form a circle with the distance between Roosendaal and Zeist as radius. An automatic arrangement was used at the receiver to count the number of faulty calls, correct calls and "misses."

"Misses" were calls which were not received. Faulty calls were calls which came through but in which the receiver recorded a wrong coded digit.

In the first series of tests 75% of the calls were received incorrectly and 17% were misses, while 8% were received correctly. This was more than enough to encourage us to redouble our efforts. By fitting suppressors on the car and reducing the set's sensitivity to noise we obtained: 23% incorrect, 4% misses and 70% correct. Then the sensitivity of the tone detector, which, as a result of the noise, was too near the operating sensitivity, was adjusted before the next reception test, which resulted in: 3% incorrect, 14% misses and 83% correct. Finally, by improving the stability, we obtained the following figures:  $\frac{1}{2}$ % incorrect, 1.2% misses and 98.3% correct. With a field strength of  $10 \mu\text{V/m}$  in open

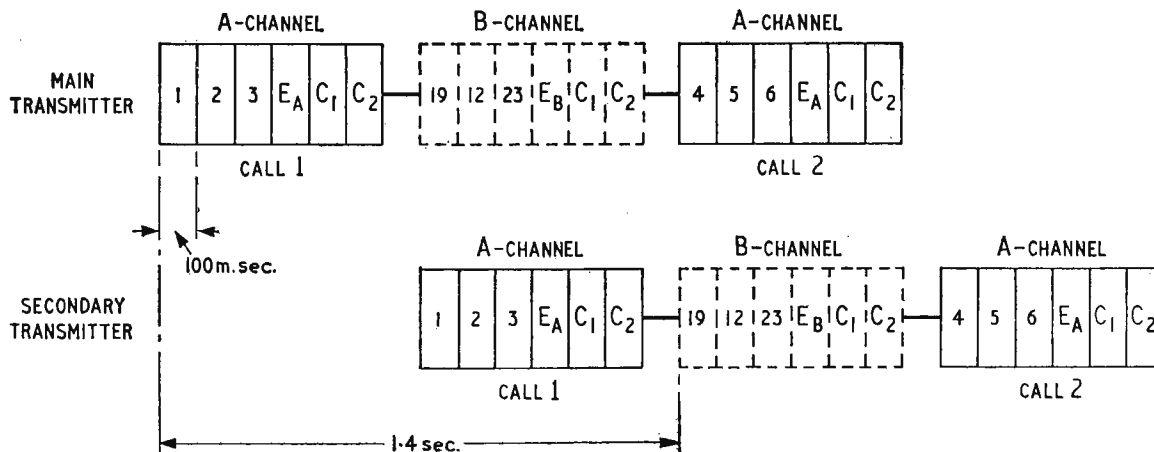


Fig. 5. Sequence of calls in A and B channels, which have 50 kc/s frequency separation.

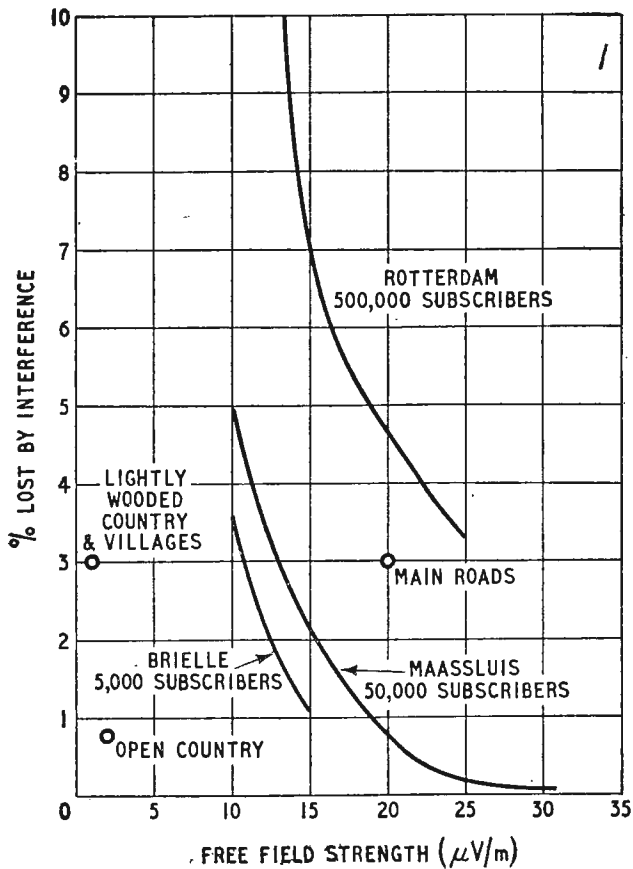


Fig. 6. Relationship between field strength and number of calls lost by interference.

country and using the repetition procedure, figures of 0% incorrect, 0% misses and 100% correct were obtained.

Fig. 6 shows the relation between field strength and chance of interference (misses) if reception takes place not in the open country but in towns of various sizes. It will be seen that 20  $\mu\text{V/m}$  is a practical field strength for small towns ranging in size from Brielle with 5,000 inhabitants to Massluis with 50,000. At Rotterdam more than 100  $\mu\text{V/m}$  is needed to ensure reliable reception in narrow streets. With the field strengths shown in Fig. 4 all the larger towns have a field strength of over 200  $\mu\text{V/m}$ . Only Enschede, Hengelo and Oldenzaal are close to the minimum acceptable figure.

Finally, a word or two about the line part of the transmission path from calling party to calling party. To contact the Simofoon service from a telephone set it is necessary to dial a fictitious district exchange number. The number 065 has been allocated for this purpose. As 50,000 subscribers have to be accommodated and only four digits are available after the second dialling tone, part of the "exchange" number has to be used for this purpose. So we dial not 06500 but 06501, 06502, etc., and consequently we can provide service for 6 groups of 9,999 subscribers. The transition from the 10-digit dial to the 30-tone calling system can also be effected by this arrangement. The appropriate selector level in the exchange is seized, so that the selectors whose task it is to handle an 065 number automatically switch to the overflow group to Amsterdam or Rotterdam, where the relay sets for the common control equipment of the Simofoon service are installed (Fig. 7).

An electronic system comprising a store, registers and code translators, and operating on the scanning principle, now deals with the calls received. The calls are entered in a central register and tested for

intelligibility. If the Simofoon number does not exist, the telephone subscriber receives "number unobtainable" tone. If it does, he is informed by the talking machine that his call has been accepted. He can then replace his telephone. The transmitting and repeating registers ensure that the appropriate modulation is applied to the transmitters. The auxiliary transmitters receive the tone signals via carrier programme circuits.

When more calls come in than can be dealt with directly, a queuing circuit determines the sequence in which calls are recorded in the register. This arrangement means that use of the "engaged" signal is almost unknown in the case of calls to the Simofoon service, being confined to failures of the system.

Every possible precaution has been taken to avoid failures. All the transmitters are installed in duplicate. They operate at half power, each on its own aerial. If a transmitter or its aerial fails the power of the remaining half is doubled, so that the service continues without interruption.

Although the service will not be officially inaugurated until the second half of 1963, the Dutch public and business circles are already showing considerable interest. Many orders have already been booked and from an extremely varied range of groups. It is beyond the scope of this article to say anything more on that subject. I should like nevertheless to make one exception, namely the use of the service as an alarm system.

For calls to rescue teams, firemen, etc., it is common practice to use a cable network connecting the homes of those concerned and setting off a ringing signal when alarm is given. If facilities for answering are not required, the Simofoon has a number of advantages to offer in this direction, namely:

1. The members of the team or crew need not be confined to their homes; being on call does not prevent them from going visiting, for instance, or being outdoors for other purposes. They can therefore be paid less.
2. At the end of a period on call, the Simofoon can be transferred to the man coming on duty. Considerable saving is possible here.
3. Changes of address involve no extra expense. This is a great advantage over a cable system, where the expenses may be considerable.
4. No time is lost by changes of address. The person concerned remains continuously accessible. In a cable network the cable-laying and splicing may take days.
5. The coding facilities can be used to give information, e.g., where the person concerned has to report, or the size of the fire, etc.
6. The alarm can be given simultaneously *all over* Holland. If required, for instance, alarm can be given on the oil-field in Drenthe while at the same time the persons concerned at The Hague are notified.

When the Simofoon is employed as an alarm, use is also made of accessories which can be supplied by the PTT on request. The receiver, for instance, can be equipped with a removable chassis on which the dry cells can be mounted (version I). This chassis can be replaced by another on which a metal rectifier may be mounted (version II). In addition to the rectifier there is room for half of the dry cells used in version I. Alternatively, the chassis can accommodate a rectifier and six relays

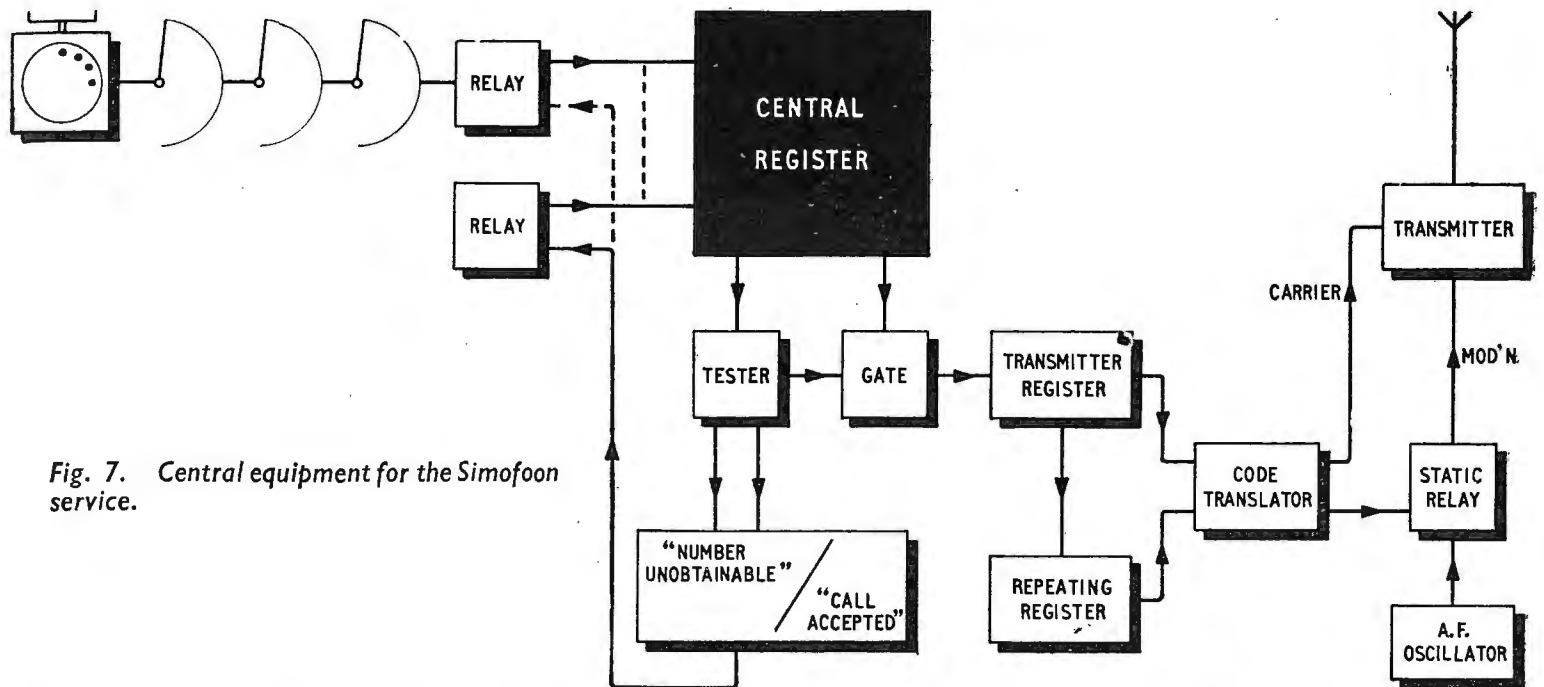


Fig. 7. Central equipment for the Simofoon service.

(version III). When so fitted, the Simofoon receiver acts as a remote-switching device or as an alarm.

Version III can be circuited so that protection is obtained against mistakes made by telephone subscribers wishing to call a Simofoon subscriber. Suppose that an alarm system consists of a number of receivers all having the same number, e.g. 1234. If alarm has to be given, this number will be dialled, followed by, say, code digit 1. If a telephone subscriber wanted to dial 1235 and also code digit 1, but made a mistake and dialled 1234, alarm would be given. The protective arrangement consists in circuiting the version III alarm receivers so that the set does not react upon receipt of the correct call, i.e. 1234 + code digit 1, but waits for several minutes for a call reading 1234 + code digit 5. When the call is dialled again, it is followed now by digit 5, and only upon receipt of this does the alarm operate. As telephone subscribers will never call the same

Simofoon subscriber twice inside a few minutes, protection is consequently ensured.

This device does not give protection against sabotage. A precaution against the latter possibility is to keep secret the number to be called. To speed up the process an automatic impulse transmitter can be used which effects the complete call once an alarm button has been pressed. Should the number nevertheless leak out, it is possible to have the digit combination changed, just as a safe combination can be changed, but then it is up to the authority to ensure that the new combination is kept secret.

There is another possibility associated with double dialling: up to 30 code signals can be distinguished by incorporating a 30-relay unit. Even without this unit it is possible to achieve the same result by reading the lamps as the call proceeds.

Fig. 8 illustrates the Simofoon receiver for normal use. On the left, towards the rear, there is a switch with three positions: Off—intermediate position—on. With the switch in the middle position, four pilot lamps should light up to show that all the filaments and the dry battery are in working order. On the right, also towards the rear, there is a push-button which will cause the lamp on the left to light up if the field strength is sufficient for reliable reception. On the right towards the rear is the telescopic aerial. On the front left is the extinguishing button, which douses the three code lamps in the middle at the front. The code digit is found by adding up the figures under the lamps that light up. The button at the front right is a clamp under which pieces of paper listing the agreed code signals can be secured. These are then immediately to hand if an unusual signal is received.

The PTT will rent the Simofoon receivers to users at fixed monthly rates. The users are responsible for keeping them in good condition and for replacing the dry battery.

If a set develops a fault, another set with a different call number is issued. This eliminates the great deal of work that would be necessary if, before a set was issued, it had to be altered to the number for which the faulty set was adjusted. This is not an excessive hardship for the user, for his number is known only to a few people and these can be contacted in his immediate vicinity (home or office).

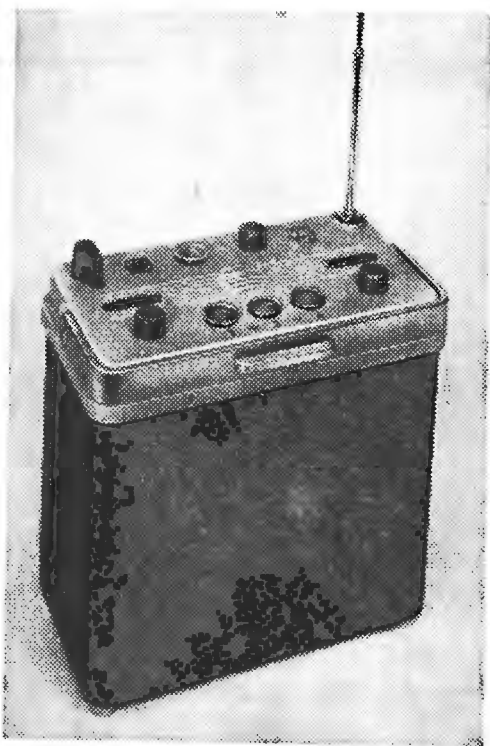


Fig. 8. The Simofoon transistor receiver developed by Philips in collaboration with the Netherlands Post Office.

# I.T.A.'s NEW LONDON TOWER

MEETING PRESENT AND ANTICIPATING FUTURE NEEDS

**T**HE aerial tower from which the first London transmissions of the Independent Television Authority were made in 1955 is a 200 ft. lattice structure at Beulah Hill, Croydon. It carried a straightforward omnidirectional Band III aerial, had an effective radiated power of 120 kW, uniformly distributed in the horizontal plane, and has served its purpose well in establishing the I.T.A. service over London and the neighbouring counties.

Experience has shown the need to extend the service area substantially

to the north and north-west and to reduce it in other directions—notably to the south-west, where interference with the I.T.A. station working on the same frequency at Stockland Hill, Devonshire, would otherwise be serious, and to the east, south-east and south to minimize interference with Continental stations.

## Electrical Characteristics

To meet these needs a new aerial was commissioned from E.M.I. Electronics Ltd. with B.I.C. Con-

struction Ltd. acting as sub-contractors. The specification to be met was as follows:—

Direction	E.R.P. (kW)
North-west	400
North	200
East, South-east & south	100
South-west	50

The 80-ft. top section was assembled at Hayes, using the foundation of steelwork forming part of the mast structure. This top section is parallel and square and carries eight stacked "rings" of dipoles mounted on reflector panels  $\lambda$  in length at the Band III mid frequency. Twin stacked pairs of dipoles are mounted on the north- and south-facing panels, but the east and west panels carry only single stacked pairs. The position and phasing of the dipoles in a single ring were first adjusted to give the salient features of the required radiation polar diagram. This inevitably contains a number of nulls due to interaction between dipoles, and in the complete assembly the technique known in the vernacular as "null smudging" is applied, the dipoles in adjacent rings being slightly offset to fill in the gaps in the required radiation pattern. The vertical as well as the horizontal pattern must be treated in this way. The main beam is deflected downwards only  $0.5^\circ$  from the horizontal but there are a number of weaker downward-firing lobes, which, when blended with about 20% of "fill-in," give ample signal strength for viewers in the vicinity of the station.

To verify calculations and make final adjustments, tests were made on a revolving test mast in open country near the E.M.I. works using the transmitting aerial as a receiver for signals from a low-powered transmitter about half a mile away.

## Tower Structure

Meanwhile, work had been proceeding on the tower base. The site area was restricted and the base width (60 ft.) is only half that of the nearby B.B.C. television tower at Crystal Palace. To prevent variation of the field strength due to tilting of the horizontal main beam the specification nevertheless called for a maxi-



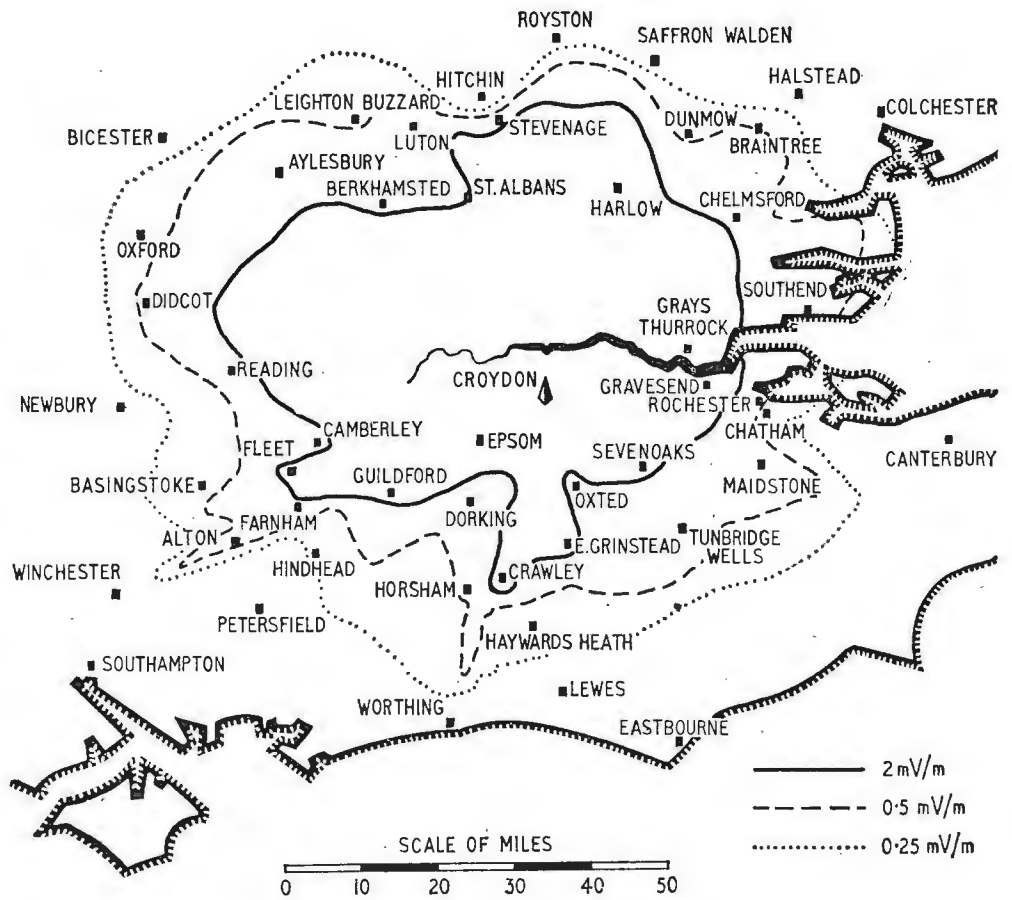
*This aerial photograph (by Barnet Saidman, F.I.B.P., F.R.P.S.) emphasizes the slim design of the new 500-ft. I.T.A. television tower at Beulah Hill, Croydon, and incidentally the small area of the available site. The old 200-ft. aerial is just discernible to the right of the new tower.*

imum deflection of not more than 1 degree of arc (10 inches at the top of the tower) for a wind speed at the top of 100 m.p.h. The difficulty of the designers was further increased by the stipulation of the aerial manufacturer that the width of the sides of the top section could not exceed 5 ft. In making these calculations account had to be taken of the possibility of further extensions of height by, for example, u.h.f. aerials on candelabra masts at the corners of the top platform.

Bore holes 40 ft. deep revealed clay foundations easily capable of bearing the deadweight of the tower (250 tons) and of the concrete foundations (1,040 tons). Each leg of the tower is supported on a block 20 ft. square and buried 15½ ft. deep to help in resisting by the principle of the "friction wedge" of the overlying earth the uplift force due to wind pressure. High-tensile steel members of cruciform section were chosen to give minimum windage. Accurate cutting and drilling of the members is essential and was carried out at the Hereford works of Painter Bros. Ltd. (a member of the B.I.C.C. group) on full-scale "loft" drawings, after the manner of ship-building. Each member was hot-dip galvanized before assembly, and it is not expected that any painting or other maintenance will be necessary for 4 or 5 years.

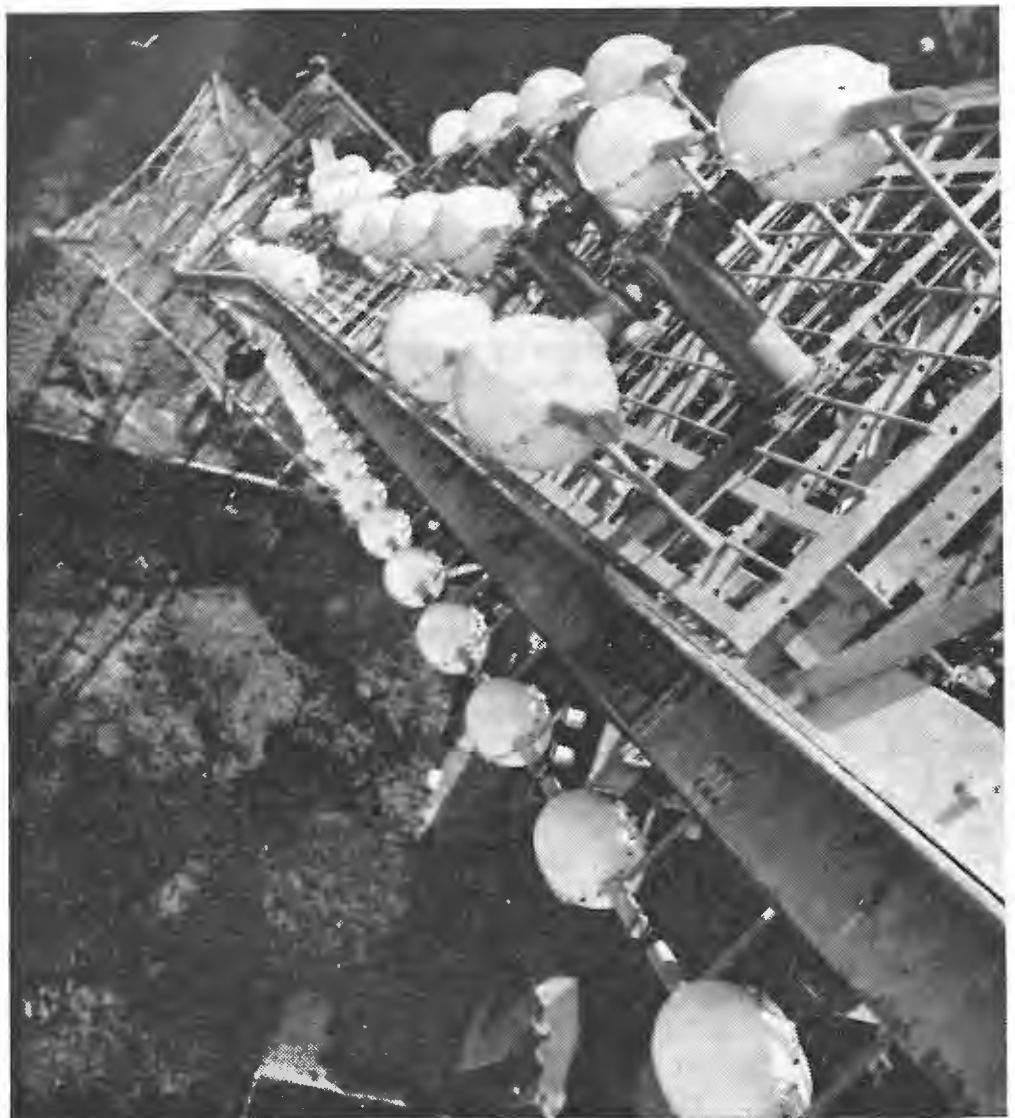
A box girder runs up the centre of the tower and supports the coaxial feeders. There are two of these supplying separate 40 ft. sections of the aerial to give continuity of operation at reduced power in the event of breakdown. The feeders are 3½-in diameter semi-flexible aluminium outer tubes with coaxial centre conductors spaced by laminated polystyrene helical tapes. The feeders were supplied on 12-ft diameter drums from which they were winched up from the base of the tower into position in less than 4 hours. Dried air is pumped up the feeders to all junction boxes and the 2½-in diameter dipoles, the latter being protected externally from the effects of snow and ice by pods of plastic material extending 30 per cent of the length from the centre feed points.

Having completed this project the I.T.A. is now in a position, as far as the "hardware" is concerned, to meet any future expansion of its services in the London area which it may be called upon to make by the Government. It also has the satisfaction of knowing that the design has the approval of the Royal Fine Arts Commission.



Estimated coverage of the London I.T.A. station (Channel 9) from the new aerial. Radiation has been increased to the north-west and reduced to the south-west, south-east and east.

This view from the top of the tower shows clearly the offsetting of dipole pairs on the south side of the tower.



# WORLD OF WIRELESS

## 625-line Test Card

SINCE the recent introduction of the 625-line test transmissions from Crystal Palace on channel 44 (vision 655.25Mc/s, sound 661.25Mc/s) the B.B.C. has been using an "interim test card." This is based on the American 525-line card designed by the Society of Motion Picture & Television Engineers. Although it will eventually be superseded by a specially designed 625-line card it is felt that readers in the service area of the London transmitter may like to know the significance of the design.

**Picture Size:** The test card should just fill the viewing aperture with the tips of the centring arrows indicating the picture limits.

**Bandwidth and Resolution:** The four wedges of converging lines are for judging resolution. The vertical wedges are for judging the horizontal resolution which, in the British 625-line standard, extends to 5.5 Mc/s. The numerical scales next to the vertical resolution wedges are related to the video frequency of the 625-line television system as follows: 4 Mc/s corresponds to 310 on the wedge scale, 5 Mc/s to 390, and 5.5 Mc/s to 430.

**Contrast:** A 5-step contrast pattern appears on each side of the test card.

**Scanning Linearity:** The small circles at each corner of the test card should be of equal size.

**Low-Frequency Response and Reproduction of Edges:** In the centre of the test card is a black circle within a white circle, which may be used to check the low-frequency response.

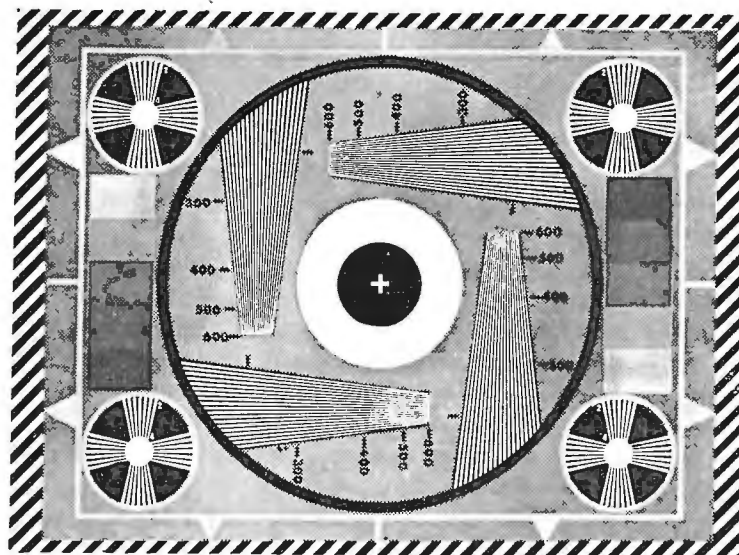
**Uniformity of Focus:** The wedge patterns within each circle at the corners of the test card should be resolved uniformly.

## Communication Satellites

THE first international conference on communication satellites, held at the I.E.E. at the end of November, drew delegates from 14 overseas countries. Of the 270 engineers who attended the five-day conference 44 came from overseas. Its purpose was to pool ideas and experience and to provide a forum for discussion of the problems involved, both technical and economic, in providing an operational system.

Many aspects were covered by the 60 or more papers. One of them by Dr. R. M. Wilmotte, described America's second communications satellite, Relay, which has been engineered by R.C.A. Although similar in concept to Telstar it differs from it in many respects. Its wideband transmitters give a radiated power of 10W—four times Telstar's output. In the interests of reliability all equipment except the telemetry encoder is duplicated. Its prescribed elliptical orbit has a perigee of 800 n.m. and an apogee of some 4,500 n.m. and, with an inclination of 48° to the equator, allows a longer period (one hour) of mutual visibility in the U.S.A. and Europe. In addition to the stations in France, the U.S. and U.K. which took part in the Telstar experiment stations in Brazil, Italy and Germany are participating in the Relay project. It is interesting to note that these stations are not employing horn radiators as in the U.S. and France but paraboloids as at Goonhilly.

A. C. Clarke's prophetic proposal, in our October 1945 issue, to use three synchronous orbiting satellites to give world coverage will come one stage nearer fulfilment when the satellite Syncom (for synchronous communications) is launched later this year. The 77-pound satellite is one of three built by Hughes Aircraft Company, of California, under a \$4M contract awarded by



the National Aeronautics and Space Administration. The three satellites will be for experimental use only and, therefore, of limited life and communication capacity.

## Electronic Telephone Exchange

ONE of the first electronic telephone exchanges to go into public service in Europe was opened on December 12th by the Postmaster General, the Rt. Hon. Reginald Bevins. The exchange, which is at Highgate Wood in North London, has eight hundred lines. It uses time-division multiplexing with pulse amplitude modulation. This enables one hundred speech channels to be carried simultaneously on a single "highway." Various aspects of this exchange were discussed in a number of papers given at the 1960 I.E.E. Conference on Electronic Telephone Exchanges (see p. 8 of our January 1961 issue). Three further electronic exchanges are now being built: two of these, at Pembury and at Goring-on-Thames, will use time-division multiplexing with pulse amplitude modulation; the third, at Leighton Buzzard, will use space-division multiplexing. All three of the new exchanges will be fully transistorized. The design and construction of the new electronic exchanges is the result of co-operation between the G.P.O. and five principal manufacturers of exchange equipment: A.E.I., A.T. & E., Ericsson, G.E.C. and S.T.C. This work has been co-ordinated by the Joint Electronic Research Committee which was set up in 1956 and on which are represented these five firms together with the Post Office.

**Anglo-American Conference.**—Four American and two British societies are jointly sponsoring the first International Telemetering Conference which will be held at the I.E.E. headquarters, Savoy Place, London, W.C.2, during the week beginning September 23rd, 1963. The American sponsors are the I.E.E.E., American Rocket Society, Institute of Aerospace Sciences and Instrument Society of America with the Brit.I.R.E. and the I.E.E. in this country. An exhibition of telemetering equipment will be held concurrently with the conference the venue for which has not yet been settled. This is being organized by a joint British and American committee and particulars for exhibiting are obtainable from McGavock Associates, 3820 East Colorado Boulevard, Pasadena, California, U.S.A.

**I.Q.S.Y.**—As a companion exercise to the International Geophysical Year (1957-58), which took place during a period of maximum solar activity, a similar programme of investigation during the waning portion of the solar cycle is being planned for 1964 and 1965. Details of the general scientific objectives of the International Quiet Sun Years (I.Q.S.Y.) are given in the provisional programme drawn up by the international committee, of which Dr. W. J. G. Beynon (Swansea University) is president, and distributed by the Royal Society. Of particular interest to *Wireless World* readers is the programme covering the ionosphere investigation which is “aimed at completing studies of the solar cycle dependence of ionospheric properties initiated during I.G.Y.”

A new television relay station at Stewnor Park, near Barrow-in-Furness, to be known as the Morecambe Bay station, was brought into service by the B.B.C. on December 3rd. It is the first of the B.B.C.’s television relay stations to use the “split-translator” technique. The receiver section of the translator—sited on high ground about a mile away—receives the transmissions from Holme Moss on Channel 2 and produces signals at an intermediate frequency which are passed by s.h.f. radio link to the transmitter section at Stewnor Park, from where they are re-transmitted on Channel 3 using horizontal polarization.

**Rank-Bush Murphy Ltd.** is the new registered trading name of Murphy Radio following the latter’s merger with Bush Radio. Operationally, R-BM comprises the following divisions of the Rank Organization: Bush Radio Division, Murphy Radio Division, Murphy Electronics Division, General Radiological Division and Solus-Schall Division. Bush and Murphy brand names will retain separate identities while development and production in the radio and television field is being integrated. Managing director of R-BM is Dudley Saward.

**Borough Polytechnic** has divided its former Department of Electrical Engineering and Physics into two parts—one a separate Department of Electrical Engineering, which has as its head V. Pereira-Mendoza, M.Sc.Tech., M.I.E.E., and the other the Department of Physics under the headship of A. J. L. Collinson, B.Sc., A.M.I.E.E.

**Graphical Symbols for Telecommunications.**—Supplement No. 5 to British Standard 530 is entitled *Logic and Functional Symbols*, and is mainly intended to assist designers, students and maintenance staff concerned with automatic switching, computers and similar applications. Copies of the standard may be obtained from the B.S.I., 2 Park Street, London, W.1, price 5s.

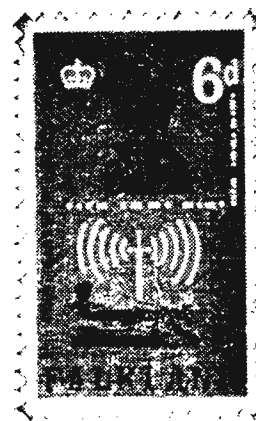
#### INFORMATION SERVICE FOR PROFESSIONAL READERS

The reply-paid forms introduced recently to replace the postcards hitherto included have proved to be very helpful to professional readers, judging by the number of forms returned to us. This improved *Wireless World* service is therefore being continued.

The forms are on the last two pages of the issue, inside the back cover, and are designed so that information about advertised products can be readily obtained merely by ringing the appropriate advertisement page numbers. Space is also provided for requesting more particulars about products mentioned editorially.

By the use of these forms professional readers can obtain the additional information they require quickly and easily.

The golden jubilee of radio communication in the Falkland Islands has been marked by the issuing of three commemorative postage stamps. All three stamps include the Annigoni portrait of the Queen and the islands’ call sign, VPC, in morse. The 6d stamp also includes an illustration of a morse key, the 1s, an early 2-valve receiver and the 2s, a rotary spark transmitter



The Engineering Institutions Joint Council has been set up by thirteen leading bodies of professional engineers in the U.K., including the I.E.E. and Brit.I.R.E., to “take action upon matters of common interest relating to the advancement of engineering and the dissemination of knowledge in that field.” The Joint Council has its office in the Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, S.W.1. Chairman is Sir Kenneth Hague and honorary secretary is K. H. Platt, M.B.E., B.Sc.

**Tall Storeys.**—Currently the world’s tallest structure, a 1,749ft all-steel television tower at Columbus, Georgia, is beaming video pictures to an area of more than 25,400 square miles stretching from the Gulf of Mexico in the south, the border of Florida to the west and Atlanta in the north. In Europe a modest 1,383ft television tower has been added to the Leningrad skyline bringing a million more people within range of Russia’s TV network.

The Hughes Medal of the Royal Society has been presented to Professor B. Bleaney, F.R.S., Dr. Lee’s professor of experimental philosophy and head of the Clarendon Laboratory, Oxford, for his “distinguished studies of electrical and magnetic phenomena and their correlation with atomic and molecular properties.”

**Anglo-Japanese Commercial Treaty.**—The Board of Trade has issued an amendment to the import quotas given on page 578 of the last issue. With reference to “parts of transistor radio apparatus”, the annual rate for 1963 should read £250,000 and not £200,000 as quoted.

**B.K.S. Course.**—“Filming and Telerecording for Television Programmes”: A course of five lectures to be held by the British Kinematograph Society on consecutive Monday evenings commencing February 18th. Fee 3gn; applications to the Society, 164 Shaftesbury Avenue, London, W.C.2.

**Transistor Course.**—A ten-week course on special applications of transistors will be held at the Wandsworth Technical College, London, S.W.18, on Tuesday evenings from January 8th. Fee 30s.

**Firato 1963.**—The next international radio and electronics exhibition to be held in the Netherlands has been fixed for Sept. 13th-22nd and will be held in Amsterdam.

The Society of Instrument Technology has moved its London offices from Queen Anne Street to 20 Peel Street, W.8 (Tel.: Park 3755).

**82 Channels on all TV Sets.**—Similar bills, passed by both Houses of the American Congress, require that all future television sets sold in inter-state commerce be constructed to receive all v.h.f. and u.h.f. television channels. Imported receivers are also included. The bill leaves it to the F.C.C. to set up regulations to bring about the shift to all-channel operation, and to establish a time schedule.

# Personalities

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**Sir Willis Jackson**, F.R.S., professor of electrical engineering at Imperial College, University of London, has been appointed chairman of the Television Advisory Committee in succession to **Admiral Sir Charles Daniel**, K.C.B., C.B.E., D.S.O., who has resigned after 10 years' service. Sir Willis Jackson returned to academic life last year although still continuing as a research consultant to A.E.I. He had been director of research and education to A.E.I. (Manchester) since 1953. For the previous seven years he had occupied the chair of electrical engineering at Imperial College. The eleven-man T.A.C. is set up by the Postmaster General to advise him on the development of television and v.h.f. sound broadcasting.

**Sir Gordon Radley**, K.C.B., Ph.D., is now chairman of the board of directors of Marconi's W/T Company in succession to **Lord Nelson of Stafford**, who remains a director of the company but has relinquished the chairmanship in view of his appointment as chairman and chief executive of the English Electric Company, the parent organization. **F. N. Sutherland**, C.B.E., M.A., has been appointed deputy chairman of the Marconi board, while still retaining full executive responsibility as managing director of the company.

**Frederick E. Terman**, D.Sc., the well-known author of "Radio Engineering," has been nominated by the American Institute of Radio Engineers for the Founder's Award which is given only occasionally for outstanding contributions to radio engineering. The citation reads "for distinguished leadership in the organization and administration of, and contributions to, scientific research and education." Dr. Terman is vice-president and provost of Stanford University, California, where, except for the war years, he has been a member of the staff since 1925. During the war he organized and directed the radio research laboratory set up at Harvard University by the U.S. Office of Scientific Research and Development and was concerned mainly with the development of radar countermeasures.

**Leonard Lewin**, A.M.I.E.E., of the Standard Telecommunications Laboratories at Harlow, Essex, is to receive the W. R. G. Baker prize of the American I.R.E. which is "awarded" to the author of the best paper published in the I.R.E. transactions of the professional groups." His paper was entitled "On the Resolution of a Class of Waveguide Discontinuity Problems by the Use of Singular Integral Equations."

**J. W. Alexander** has joined 20th Century Electronics Ltd. as project engineer on photoelectric devices. He has previously worked on klystron development at English Electric Valve Company and on various techniques connected with television camera tubes. **A. F. Challis**, Grad.Brit.I.R.E., has joined the staff as a project engineer working on the development of electronic storage tubes. **E. Cohen** is engaged as a project engineer in the Special Tube Division. For the past two years he was with the Central Electricity Generating Board working on thermionic energy conversion techniques. Previous to this he was at the G.E.C. Research Laboratory. A fourth appointment is that of **F. J. Tolhurst**, Grad.I.E.E., as project engineer on fission chambers. Mr. Tolhurst was previously with English Electric Valve Company.

**J. S. McPetrie**, C.B., Ph.D., D.Sc., director-general of electronics research and development at the Ministry of Aviation until a few months ago, has been retained by Racal Electronics as technical consultant. Dr. McPetrie, who is 60, joined the Government scientific service in 1925 at the National Physical Laboratory where he stayed until 1943 when he was appointed radio physicist to the British Joint Services Mission in Washington. For six years from 1944 he was superintendent of the Signals Research & Development Establishment and from 1950 to 1958 was head of the radio department of the Royal Aircraft Establishment. His successor at the Ministry of Aviation is **Dr. W. H. Penley**, C.B.E., who was deputy director of the Royal Radar Establishment, Malvern.

**A. P. Monson**, superintendent engineer, B.B.C. sound broadcasting, since 1957, has been appointed chief engineer, sound broadcasting, in succession to **F. Williams**, C.B.E., B.Sc.(Hons), M.I.E.E., who has retired after 37 years' service with the B.B.C. After being engineer-in-charge at various stations Mr. Williams became assistant superintendent engineer, studios, in 1946. Since 1957 he had been in charge of sound broadcasting engineering. Mr. Monson joined the Corporation in 1933 and has been concerned almost exclusively with sound recording. He was superintendent engineer (recording) from 1950 till 1957 when he was appointed superintendent engineer, sound broadcasting.

**A. Salmon**, Ph.D., B.Sc., F.Inst.P., A.M.I.E.E., has been appointed deputy sales manager of the Scientific Apparatus Department, A.E.I. Instrumentation Division. After obtaining a B.Sc. degree in physics at Liverpool University in 1948, he joined the A.E.I. Research Laboratory at Aldermaston, and was concerned with electrostatic accelerators until 1954, when he was attached to the Atomic Energy Research Establishment at Harwell. Dr. Salmon received his doctorate from Reading University in 1953 for a thesis on angular correlations in nuclear reactions.

Three appointments in the recently constituted Industrial Products Division of E.M.I. Electronics have been announced. **R. J. Hummerston**, who becomes sales manager for machine tools, has been with E.M.I. since 1941 when he joined the company at the age of 15 as an apprentice in the Technical Training School. **P. H. U. Maguire** has been appointed manager of automation systems. Since he joined E.M.I. in 1953, Mr. Maguire has concerned himself with military electronics, data processing equipment and most recently systems studies. **F. W. Hartley**, now chief engineer, has been with E.M.I. since 1948 and has worked at the company's Hayes and Feltham plants on electronic components, transformers and industrial engineering projects.

**Pierre Buloz**, managing director of CSF—United Kingdom, the recently formed British subsidiary of the French Compagnie générale de télégraphie Sans Fil, joined the staff of CSF in 1959. M. Buloz, who is 43, and for part of the last war was in the Air Attaché's office at the French Embassy, Washington, was on the staff of the French National Telecommunications Research and Development Centre from 1949 for 10 years.

**R. F. Wilson**, B.Sc., A.R.C.S., writes in this issue on the use of aluminium oxide as a dielectric, on which he has been undertaking research at the Electrical Research Association, Leatherhead, for the past three years. Mr. Wilson recently left the laboratory to take up a position in industry. After National Service in the Royal Signals he studied at Imperial College where he obtained an honours degree in geology.



**A. H. Sheffield**, formerly of the Colonial Office and now head of the Communications Department of the Government Department of Technical Co-operation, has been appointed as a member of the Commonwealth Telecommunications Board to represent the British dependent territories and those Commonwealth countries which have not appointed their own members. He succeeds **W. J. Bigg, C.M.G.**, who has held this appointment since 1955.



**A. C. Bentley**

1945 and has been deputy secretary for the past two years.

**W. T. Ash, O.B.E., Comp.Brit.I.R.E.**, has resigned, on grounds of ill-health, his appointment as secretary of the Radio & Electronic Component Manufacturers' Federation. He has been secretary since 1944. Mr. Ash, who is 62, was with the Marconi Marine Company from 1917 to 1939 and for a few years prior to joining the R.E.C.M.F. was with British Relay Wireless. He is succeeded by **A. C. Bentley** who joined the Federation's staff as assistant secretary in

## OBITUARY

**Professor Edgar W. Marchant, D.Sc., F.C.G.I., Hon. M.I.E.E.**, professor of electrical engineering at Liverpool University from 1903 until his retirement in 1941, died at his home in Warwickshire on November 14th. He was 86. His contributions to technical literature covered a very wide field and his last article in *Wireless World* (April, 1952) dealt with pre-Heaviside propagation theories.

**Joseph L. Pawsey, F.R.S., Ph.D.**, assistant chief of the Division of Radiophysics at the Commonwealth Scientific & Industrial Research Organization, Australia, died on November 30th aged 54. Dr. Pawsey two years ago was awarded the Hughes Medal of the Royal Society for "his distinguished contributions to radio astronomy both in the study of solar and of cosmic radio emission." He graduated at Melbourne University and received his Ph.D. degree from Cambridge where in the Cavendish Laboratory (1931/2) he worked on the propagation of radio waves through the ionosphere. He was in the research laboratory of E.M.I. for several years before returning to Australia early in the war.

**P. A. Spring, O.B.E., M.Sc., A.R.I.C.**, general manager and deputy chairman of The Telegraph Condenser Company, died on November 10th at the age of 61. Mr. Spring joined the company in 1923 and was for a time in charge of research and development. He was appointed deputy chairman in 1956. Mr. Spring was also chairman of United Insulator Company & British Dielectric Research Ltd.

**Ernest B. Greenwood, B.Sc.**, works manager of Marconi's Basildon factory died on November 6th at the age of 54. A graduate of Leeds University Mr. Greenwood was for three years lecturer and demonstrator at the City & Guilds Engineering College before joining Murphy in 1932 as assistant to the chief engineer. Four years later he went to Ekco as assistant production manager. He joined Marconi's in 1951.

**Regtone, R.G.D. and Argosy** trade names now join K-B. and Ace with the takeover by Standard Telephones & Cables of Regtone Products Ltd. from Lloyd's Packing Warehouses Ltd. The £470,000 cash transaction includes the acquisition by S.T.C. of the five subsidiaries—Regtone Radio & Television, Radio Gramophone Development Co., Argosy Radiovision, United Components and Combined Radio & Television Service. The latter will be the servicing organization for all five brand names. Production of radiograms and record players will be at the Rhyl factory, sound radio and television at Hastings, with administration, engineering and special television production at Footscray. The co-ordination of production is in the hands of J. McK. McLean, recently appointed general manager of the Consumer Products Division of S.T.C. He recently returned to this country from the U.S.A. where he had been deputy area manager, Latin America, for the International Telephone and Telegraph Corporation, of which S.T.C. is a subsidiary. B. L. Muller is continuing with Regtone as sales director. Emerson products will still be marketed by Lloyd's through their subsidiary Cockburn & Gunn.

**S.G.S.-Fairchild Ltd.**—Dr. James Kendall, general manager of S.G.S.-Fairchild Ltd., announced at the company's December symposium that production of their silicon planar transistors would start in their Ruislip factory by the beginning of 1963. It is hoped that pre-production batches of "Micro-Logic" would be available by mid-1963 with full-scale production in 1964/65.

**Murphy's** production of radiotelephone equipment has been transferred from the Ruislip factory to Welwyn Garden City—the headquarters of the Murphy Electronics Division of the Rank Organization. The lease of the Ruislip factory has been acquired by S.G.S.-Fairchild (see above).

**Gas Purification & Chemical Co. Ltd.**—A group net loss of £137,767 is reported for the year ended June 30th, 1962, and this compares with a previous deficit of £45,959. During the year the group, which includes Grundig (Great Britain) and Wolsey Electronics, sold goods and services to the value of £6,797,000 (£6,762,000).

**Ultra Electronics Reorganization.**—Under a new divisional structure the operations of the Ultra Electronics Group have been reorganized into five product divisions. These are: control and instrumentation, special products, telecommunications, automatic business systems, and components.

**Controls & Communications Ltd.** have acquired the former Contracts Department of Modern Arms Co. Ltd. and have formed it into a new subsidiary company, Modern Aerials Ltd., which will engage in the design and manufacture of aerial masts and portable aerials for use with communications equipment.

**CSF (Compagnie générale de télégraphie Sans Fil)**, the large French manufacturing group whose main products are components, microwave links, radar and television systems, has several working agreements with firms in this country, notably Decca-Navigator, G.E.C. and Marconi—the latter extending over 40 years. To facilitate the already considerable two-way activities between the two countries a new company, CSF United Kingdom Limited, has been set up with offices at 1 Cadogan Place, London, S.W.1. At the official opening Dr. M. Ponte, president of the parent company, and also a member of the French National Planning

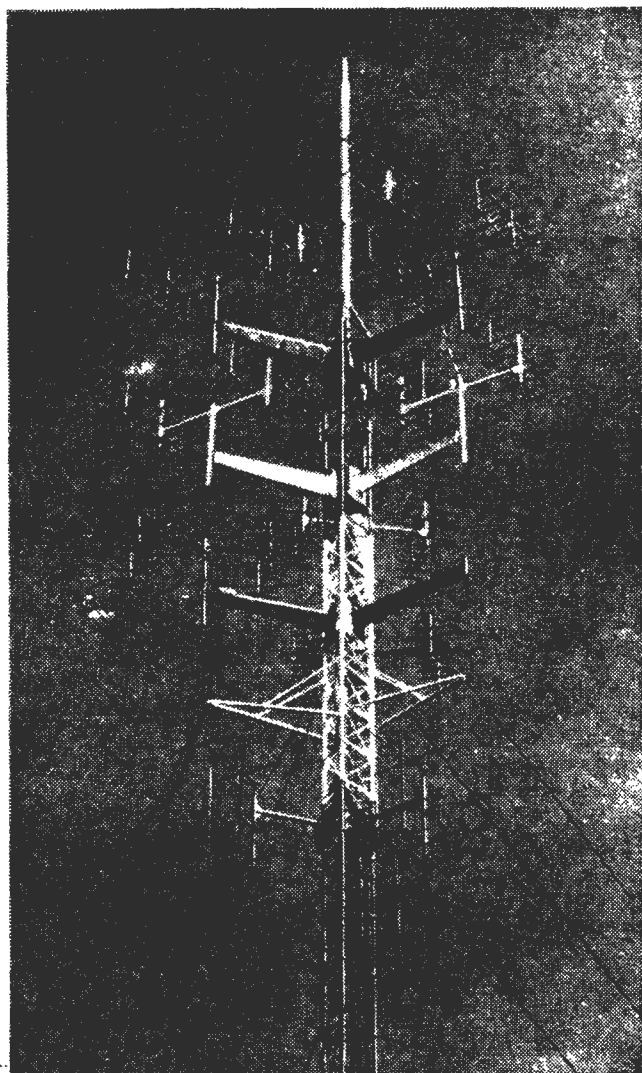
Board, disclosed that by 1965 a 50% increase of production of electronic equipment to a value of £450M was aimed at in France, of which CSF expects to contribute £100M. At present CSF's trade balance with the U.K. is adverse, with purchases in this country running in excess of £700,000 per annum.

**Proceedings of divorce cases** being held in one of the court rooms at the Law Courts in the Strand, London, are being recorded as an experiment by professional tape recorders supplied by E.M.I. Electronics Ltd. If any queries are raised on evidence given earlier in the hearing, on playback the meanings behind the voice inflections can be assessed as well as the exact wording.

**Magnetic recording tape** is now being produced by Ilford, of Essex. "Ilfotape," a ¼-in wide "long play" (0.001in thick) polished tape using a p.v.c. base, will be available from 1st January in 5-in, 5¾-in and 7-in spool sizes.

**Plastronics Ltd.**, manufacturers of injection-moulded electronic components and encapsulated assemblies, have moved to Tolpits Industrial Estate, Tolpits Lane, Watford, Herts. (Tel.: Rickmansworth 2727.)

**Seventeen vessels** of the Clan Line and Union Castle Line fleets are to be equipped with marine radar made by the Kelvin Hughes Division of S. Smith & Sons (England) Ltd.



**Belgium.**—A television and v.h.f. sound relay station at Liège, uses an array supplied by J-Beam Aerials Ltd., with associated equipment by Teleng Ltd. The array comprises nine Band III twin "double eight" slot aerials, three Band II "double four" slots, and two assemblies of four Band IV "double eight" slot aerials, which are mounted on a 150ft tower to receive Belgian, French and German stations. There are no u.h.f. transmitters in Belgium and the Band IV arrays are used to receive transmissions from Aachen.

**Chernikeeff electronic log sales and servicing** is being undertaken by Marconi Marine following an agreement entered into between the Marconi International Marine Co. Ltd. and the Submerged Log Co. (1962) Ltd. As a result the world-wide Marconi Marine depot organization is placed at the disposal of shipowners wishing to fit the Chernikeeff log, or to have existing installations serviced.

**New Agency for M.E.C.**—Bowmar Instrument Corporation of Fort Wayne, Indiana, manufacturers of electro-mechanical servo components, have appointed as their exclusive sales agents in Britain, Miniature Electronic Components Ltd., of St. Johns, Woking, Surrey.

**Protona.**—Clarke & Smith Industries Ltd., who continue to handle the U.K. distribution of the German Protona Minifon magnetic-wire recorder, are an independently controlled associate of Electric & Musical Industries Ltd. and not a division as stated in our note in the November issue (page 528).

**All component business** conducted by A. C. Farnell Ltd. is now undertaken from the company's head office at Hereford House, North Court, Vicar Lane, Leeds, 2, following the transfer of the Electronic Components Division from Wetherby.

## OVERSEAS TRADE

**In Angola** an extensive multichannel network of trunk radiotelephone and telegraph channels connecting all the main centres of population in the territory is now operational. All but one of the links use Marconi v.h.f. terminal and repeater stations in duplicate. Marconi's were also responsible for the aerial systems and ancillary radio equipment, whilst Automatic Telephone & Electric Company have supplied the carrier telephone equipment.

**SARAH**, the Search and Rescue and Homing device developed by Ultra Electronics Ltd., is now in use with the air forces of 30 countries.

**Brasilia**, capital of Brazil, is to have a Decca airfield control radar installation at the international airport to the south-west of the city. Similar equipment is in service in Venezuela and Argentina, while Decca meteorological radar is already in use in Brasilia.

**Airborne weather radar equipment** worth over £115,000 is to be supplied to Trans Australia Airlines by Ekco Electronics Ltd.

**A Tokyo commercial television station**—Nippon Educational Television Co.—has ordered £22,000 worth of 4½in image orthicon TV cameras and assorted studio equipment from E.M.I. Electronics Ltd. The cameras will operate on the American F.C.C. 525-line standard.

**An Italian nuclear reactor**, which has been constructed by a British company, the Nuclear Power Group, at Latina, near Rome, is to have closed-circuit television equipment, designed by Pye T.V.T. Ltd., to probe into its core enabling reactor channel walls and fuel elements to be inspected for defects.

**A radio interpretation system** for the Algerian National Assembly has been supplied by Multitone Electric Co. Ltd. The entire installation, complete with lognette-type receivers, was sent by air and represents the first order by a foreign parliament for this British equipment.

**Sound reinforcement and simultaneous English/Hausa translation systems** for the Regional Legislature at Kaduna, Nigeria, have recently been installed by Standard Telephones & Cables Ltd. The loudspeakers are built into the backs of the seats, allowing a locally high level of sound to be achieved before the onset of acoustic feedback.

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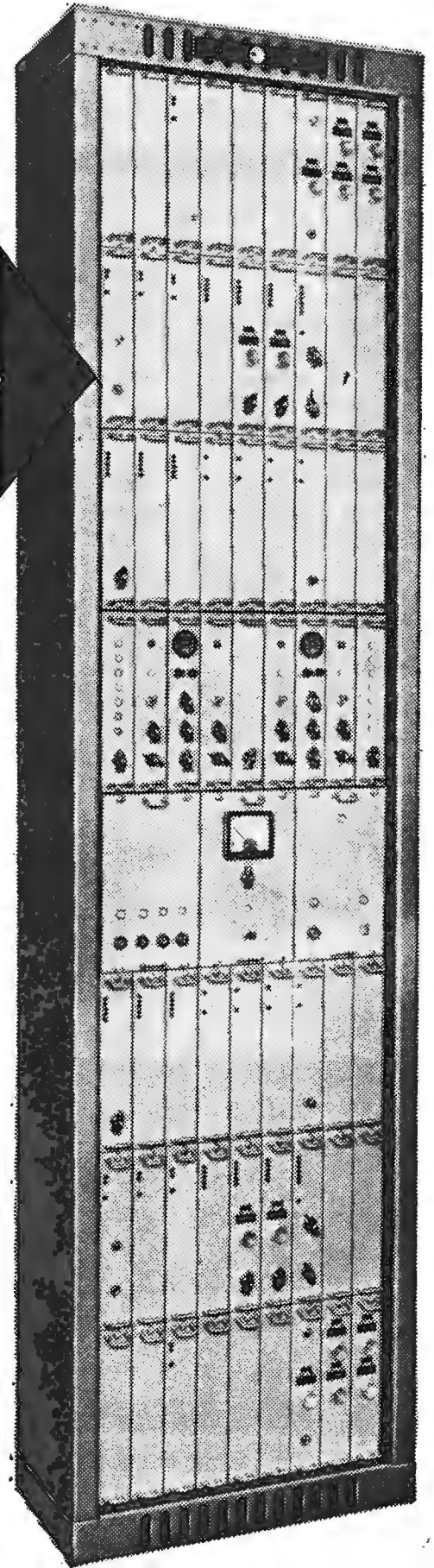
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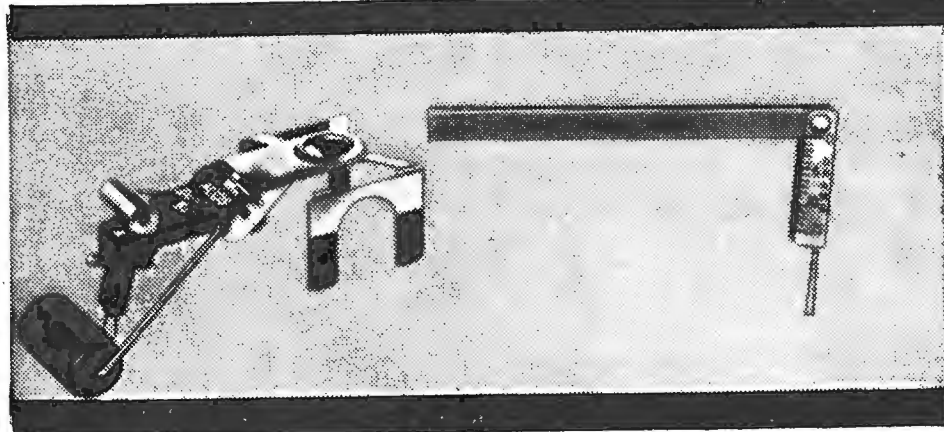
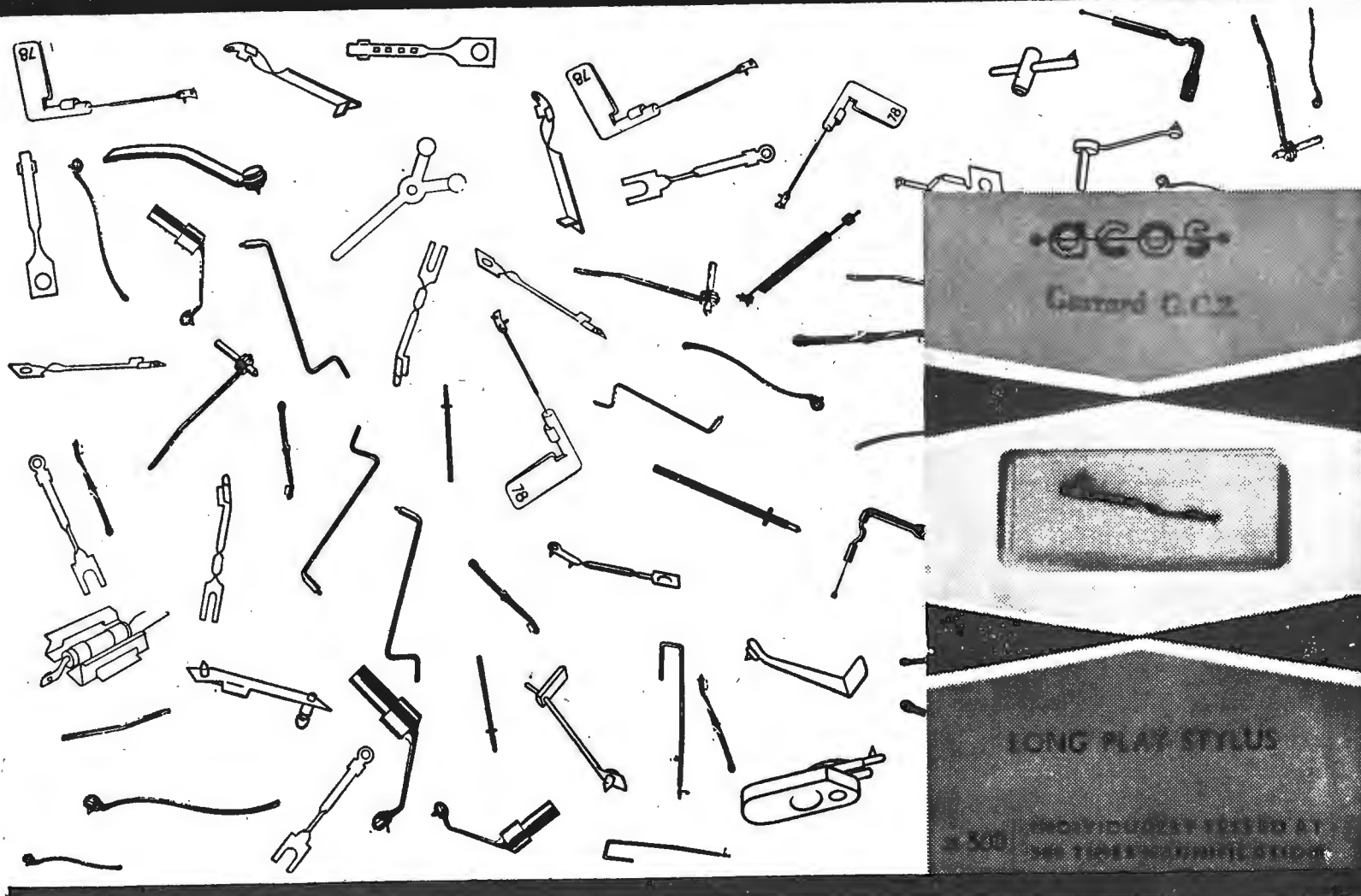



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# TRANSISTOR AMPLIFIER OUTPUT STAGES

## 1.—BRIDGE CIRCUITS

By O. GREITER

**A** GENERALIZATION need not be true in order to attract attention. Indeed, if it is false it may be striking and if it is true, it may be a platitude. With this half-concealed warning we may say that the only real problem in amplifier design is the problem of the output stage. If we are considering high quality audio frequency amplifiers we know that the use of low noise devices in the input stage will probably be adequate to deal with the question of circuit noise. Distortion and bandwidth in the low level stages may call for ingenuity in the design of both the interstage and feedback networks.

Power output stages raise problems of a special kind. In the writer's experience it has always been desirable to obtain as much power as the output devices would handle at the prescribed supply voltage. Various design considerations demand that the output stage should be as efficient as possible. This requirement may not be stated explicitly but may appear, for example, as a limitation to the current passed imposed by the size of a transformer. During the active development period of a type of amplifier we may find a mythology becoming established. For many years after the "buzz effect" had vanished from our pentodes there was a controversy about whether a triode or a pentode should be used as an output stage. Langford Smith's *Radio Designer's Handbook* (Iliffe) states (p. 547) that parasitic oscillations are sometimes encountered, that high mutual conductance valves are particularly liable to this trouble, and that class-AB2 or class-B stages sometimes suffer due to negative slope. This negative slope can be found in the low anode voltage, low current region of some tetrode characteristics but will not, of course, appear in triode characteristics. The so-called ultra-linear mode of operation in which the screen voltage follows the anode voltage should be much less liable to this kind of trouble. One hesitates to be dogmatic about this, for the effect occurs in a region to which the valve can only be brought because of leakage inductance in the output transformer. One is reassured by the fact that the triode versus pentode controversy appears to be dead.

### Advantages and Disadvantages of Using Transistors

Although the attrition of time has eliminated most of the less satisfactory valve circuits the design of transistor output stages is still extremely fluid. In many ways the transistor offers us a good deal more freedom in design. The relatively low voltage and relatively high current encourage the use of transistors in series; the availability of p-n-p and n-p-n types and their use in compound connections offer a great variety of basic circuit

types. At the same time the sensitivity of the transistor to overloads and to ill-chosen bias conditions which can give thermal run-away, the uncertainty about the transistor parameters when the temperature range is wide, and the extremely limited performance of the cheaper transistors, all make the practical design problems more difficult and less capable of assessment in purely abstract terms.

In an autocracy man votes with his legs, in a democracy with his purse. By about 1970 the manufacturers who have chosen the better circuits will be flourishing, while those who have chosen unwisely will have vanished or changed their course. All that we can safely do now is survey some of

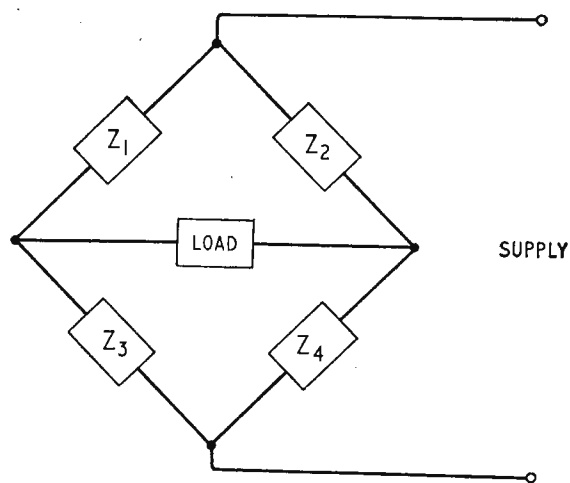


Fig. 1. This bridge circuit completely describes push-pull amplifiers.

the problems, especially those about which there appears to be some confusion, suggest some of the answers, and leave it to the reader to decide whether the balance of advantages and disadvantages has been correctly struck.

Much of the English material on high quality transistor amplifiers is based on the use of class-A output stages. This imposes a very serious limitation on the available power. Enquiries about this usually lead the commercial people to "wrap it up", in Mr. Henry Cecil's descriptive phrase. British ears are more sensitive, pink and shell-like than American ears. British walls are thinner than American walls. American watts are smaller than British watts. The manufacturer's social conscience prevents him offering us such dangerous devices: if you want to "do the ton" you must hire public address equipment. A realistic attitude, however, would be to use class-B operation and smaller devices at maximum efficiency if the aim really is limited power. Mr. Donald Campbell may drive round the Goodwood track with his

brakes full on but we may doubt whether he intends to use Bluebird for his everyday motoring.

There are two aspects of output stage design; the choice of configuration and the choice of operating conditions. We can attempt to discuss these systematically although we know that in choosing some configurations we shall automatically determine to some extent the operating conditions. We may concentrate our attention on push-pull operation, inevitable with class-B stages and advantageous even with class-A stages. At this point it is better to leave undecided whether we should consider single-ended stages at all.

Push-pull circuits are completely described by the bridge circuit shown in Fig. 1. The structure contains a combination of active devices and reactances. Since it is to be a push-pull system the number of active devices must be even, that is either two or four. The remaining arms must be reactive if they are not to dissipate any power. It is not easy to decide which practical form of this circuit should be taken first, because there is a balance to be sought between familiarity and rather uncertain logic. We may perhaps proceed best by drawing the three most common forms in Fig. 2. The first of these will be recognized as the circuit generally called a push-pull circuit, the third as the circuit commonly called the single-ended push-pull or output-transformerless (O.-TL.) stage, while the middle circuit, for reasons which are obscured by this way of drawing all three circuits, is sometimes called a full bridge circuit. From this terminology we derive the term half-bridge for Fig. 2c although it is not applied equally to Fig. 2a.

Each of these circuits can be developed in a number of different ways. The drawings have an intentional ambiguity in the symbol used for a transistor to indicate that either p-n-p or n-p-n transistors may be used and although the form used suggests a choice between common emitter working and common collector working it will be clear that the transistors may also be operated in the common base mode.

### Matching Conditions

We can now make use of the basic bridge equation which indicates that so long as  $Z_1/Z_2 = Z_3/Z_4$  there will be no flow of energy from the supply to the load. In the usual application of this we should have constant values for the  $Z_{1-4}$  and would consider only the static balance in which the load and supply frequency would be the same, in a normal amplifier zero. However, since this statement is true for all values of the  $Z_{1-4}$  it is true even if  $Z$  is changing. Thus so long as  $Z_1$  matches  $Z_2$  and  $Z_3$  matches  $Z_4$  we do not need to consider the matching of  $Z_1$  to  $Z_3$ . In the conventional form of Fig. 2a we know that we must have a fairly good match between the two transistors and that the transformer, which appears here as an inductor, must be tapped at the centre. In Fig. 2c we can say with some hesitation that  $Z_2 = Z_4$  and that therefore we must match  $Z_1$  and  $Z_3$ , the two transistors. In the circuit of Fig. 2b we see that the upper pair of transistors must be matched together, and so must the lower pair, but there is no requirement for any matching between the upper and power pairs.

The effect of the symmetry thus imposed is well

known. No matter what the law of the devices may be a push-pull drive will produce only the odd harmonics in the load although the whole load may be driven in a push-push mode by even harmonics. These can cause trouble if there is any unwanted coupling of any kind to other parts of the system. When  $Z_1$  also matches  $Z_3$  there is no push-push signal at the load and this observation is the basis for the derivation of Fig. 2c by slicing the bridge in half with a vertical cut to form two half-bridges with a node at the centre of the load. The two capacitors in Fig. 2c merely provide the anchor-point for this nodal point and if the supply has zero impedance only one, and it is clearly immaterial which one, needs to be used.

It is implicit in this discussion that the supply is a constant voltage supply but we see on reflection that a constant current source might equally well be used. The only point at which the two systems would differ would be in the choice of the quiescent working point when the transistors were operated in class-B. Constant current working is, however, such an esoteric matter that we can ignore it in this study.

### Transistor Ratings

The simplicity of the three basic circuits of Fig. 2 can prove misleading. Now that we have established the essential matching conditions we must look more closely at the rectangle marked load. It will be assumed that the transistors are ideal transistors and that they are to be operated in class-B. We know the supply voltage  $V_{cc}$  and the maximum collector current  $I_c$ . For ideal working the load on the active transistor should be  $V_{cc}/I_c$ .

Consider Fig. 2a. The load is viewed by the active transistor through a 1 + 1 : 1 autotransformer, so that we must make  $R_L$ , the actual load, equal to  $4V_{cc}/I_c$ . We could arrive at this result in another way. When the active transistor just touches the bottoming point the see-saw action of the centre-tapped inductor raises the collector of the other transistor to  $2V_{cc}$ . The transformer action produces in the load a current of  $I_c/2$ . The load resistance must be  $R_L = 2V_{cc}/(I_c/2) = 4V_{cc}/I_c$ .

Consider now the circuit of Fig. 2b. When two transistors are cut off and the other two bottomed in series with the load we have a permitted current of  $I_c$  still and we must have  $I_c = V_{cc}/R_L$ , so that  $R_L = V_{cc}/I_c$ . Both these two systems offer us a peak power of  $V_{cc}I_c$  which for our conventional sine wave operation means a signal power of  $\frac{1}{2}V_{cc}I_c$ . We see, however, that while in Fig. 2b the transistors which are cut off must withstand only  $V_{cc}$ , the cut-off transistor in Fig. 2a is subjected to a voltage of  $2V_{cc}$  at the peak.

In the circuit of Fig. 2c the symmetry condition demands that the junction point of the two capacitors should stand at  $\frac{1}{2}V_{cc}$ . When one transistor is cut off it must withstand the full supply voltage  $V_{cc}$  as soon as the other is bottomed. The load resistance will pass a current  $I_c$  with  $\frac{1}{2}V_{cc}$  applied if we have  $R_L = V_{cc}/2I_c$ . The peak power is now only  $\frac{1}{2}V_{cc}I_c$ , so that this is not directly comparable with the results for the circuit of Fig. 2a. We could fix the power initially, as we normally should. Then the transistors in the circuit of Fig. 2c would need to be operated with a load of  $R_L = V_{cc}/4I_c$  and to accept a peak current of  $2I_c$ , where  $I_c$  is now defined by the equation  $W = V_{cc}I_c$ .

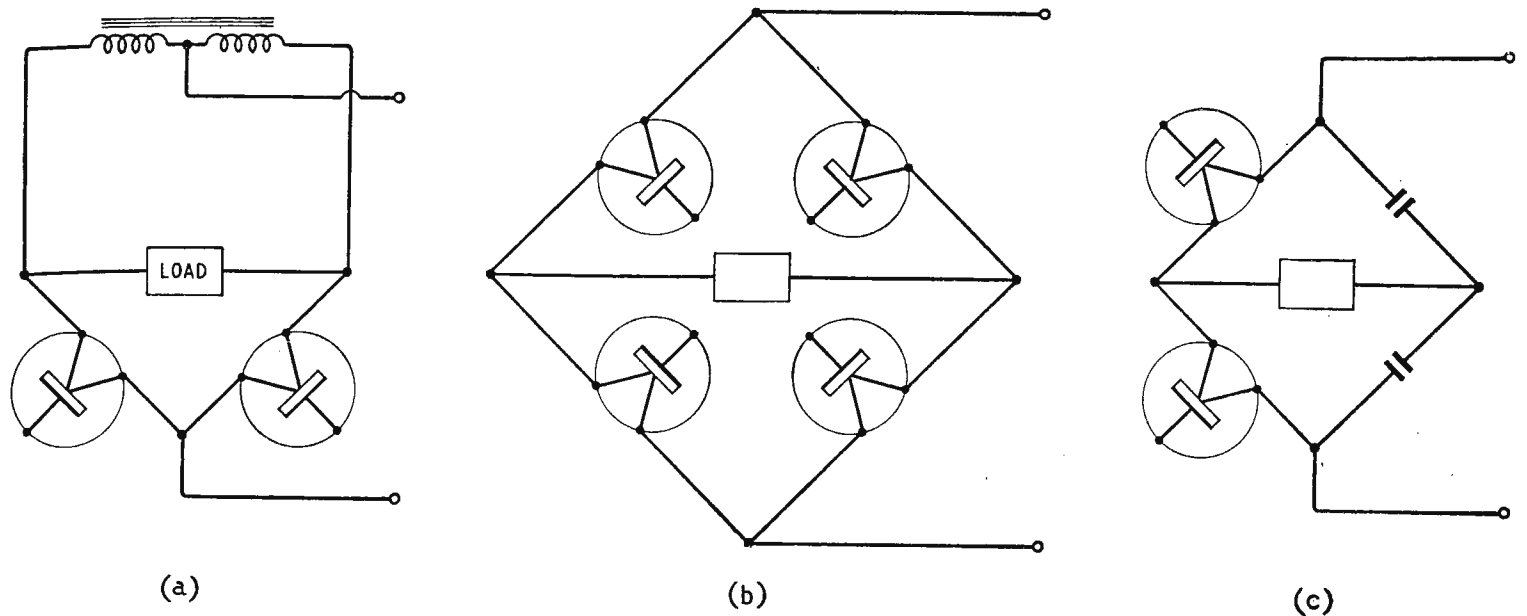


Fig. 2. Three most common forms of bridge circuit of Fig. 1: (a) push-pull, (b) full bridge and (c) single-ended push-pull or output-transformerless.

This result indicates the price of replacing two of the transistors in Fig. 2b by reactances. We must use transistors which will accept either twice the voltage or twice the current which would be used in a four-transistor system. The design conditions may virtually determine the answer, at least if we regard the question as a choice between the alternative two-transistor circuits. A system operating from a 12 volt line will not introduce any direct voltage problems if the voltage doubling circuit is used, for transistors with ratings of 32, 40, 48 and higher voltages are readily available. The current doubling circuit offers only disadvantages under these conditions, for in order to get the necessary current through the transistor we must provide rather more than twice the input electrode drive. Usually, though not necessarily, this means more than doubling the base drive.

### Voltage Doubling Circuit

The voltage rating of the transistors in a circuit of the voltage doubling type requires very careful attention. The load will normally be connected to the secondary of the transformer and the collector of the cut-off transistor will face the stray capacitance/leakage inductance structure of the transformer. These will commonly be proportioned to give the widest possible flat band, although an alternative design approach is to allow the leakage inductance to dominate the response in order to get a region in which the response falls at the rate of 20dB/decade and the phase shift is asymptotic to 90°. In either condition an output circuit will be liable to ring if driven by a square wave or by a large amplitude signal of sufficiently high frequency. The instantaneous peak voltage may then be substantially more than twice the supply voltage. This can bring the transistor into that dangerous region in which the excessive voltage and the persisting current due to hole storage correspond to a part of the characteristic which will give a negative resistance. The parasitic oscillation which may occur will usually be chiefly disturbing because it will reach earlier stages which can be blocked off. The difficulty is

no doubt preferable to the failure of the transistor

It is easy to show that this should not be a real problem at all. The nature of programme material, the control of the rate of rise of the signal earlier in the circuit, both these factors will suggest to the designer that he is not really at risk. This is probably true on a formal analysis. An economically minded amplifier designer would accept the chance that a particularly vulnerable transistor would be subjected to a particularly dangerous signal and would use linear programming methods to decide whether to use the cheaper transistor and the more generous guarantee. The cost of determining the parameters on which such a decision is to be based and the difficulty of explaining it to the commercial side of an organization suggest that the prudent designer will seek to put a curb on dividends and incentives into creative work by playing safe though the profits fall rather than seeking the truth though the heavens fall.

With the circuit of Fig. 2c, the current doubling circuit, there is commonly no output transformer. There may still be some inductive reactance in the load, however, for not only is the load usually a loudspeaker, but it is quite likely to be one of a stereo pair. This brings a new danger which can, indeed, be present with a single speaker system of any pretensions to quality. It would not be impossible to produce a 15 ohm twin feeder for connecting the speaker to the amplifier but the user is likely to take merely a length of ordinary lighting flex. All in all there will still be a fair amount of stored inductive energy here. It would, however, appear to be difficult to get a bottomed transistor to swing into reverse and for a partly on transistor to be pushed through bottoming. Consequently it is very safe to rely on the peak transistor voltage being limited to the supply voltage and for the engineer who can picture some mechanism which will produce transient over swings there is always the possibility of using fast diodes as peak catchers.

The current doubling circuit is therefore a popular choice for higher voltage operation, especially when the voltage is a matter of choice. The limited

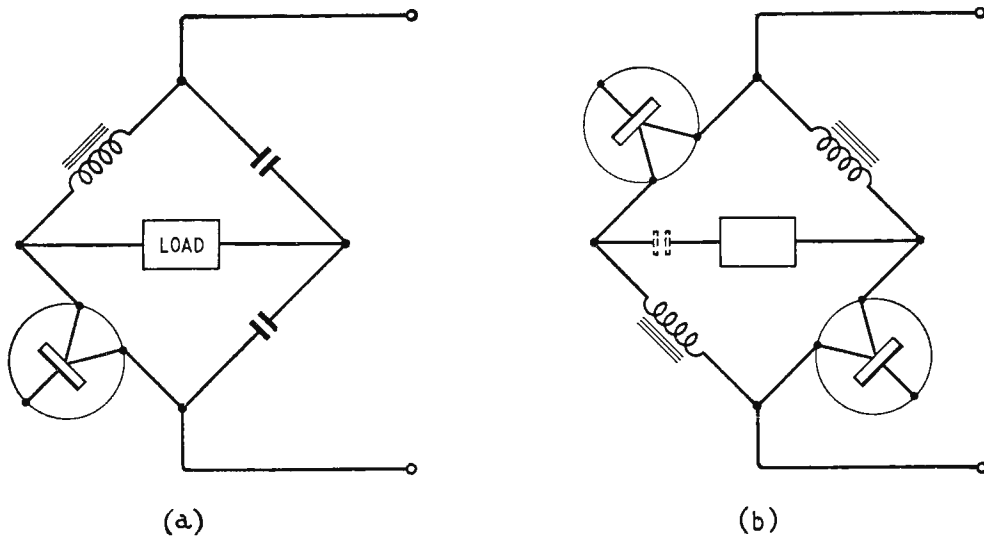


Fig. 3. Two remaining forms of bridge circuit of Fig. 1: conventional amplifiers with choke-capacity coupling to the load using in (a) one transistor and (b) two transistors in series.

range of loudspeaker impedances prevents us matching the supply voltage exactly to the transistor specifications and exposes the designer to a new temptation. It is generally believed that transistors will pass more current than the makers admit. Since the duty cycle of levels in the upper 6dB of the range is relatively small, the bold, or reckless, designer will therefore design to take a peak current of, say, three, ampères from a two ampère transistor. The conservative designer will deprecate this course of action although he may be embarrassed when he learns that the rating has been revised upwards by the manufacturer.

In some published designs the current-doubling output-transformerless circuit is used with an output transformer or auto-transformer. This arrangement is chiefly of value in the production of a general purpose amplifier, especially where it may be required to drive speakers of any impedance on a public address 50 or 100 volt line. The capacitance bridge arms are also sometimes absorbed into the power supply system. One common form is to bring out the centre-point of the supply battery, using, for example, two 12 volt batteries in series. Twin mains-operated supplies have also been used.

### Supply Requirements

Very little attention has been paid in the literature to the problem of providing the zero impedance supply which is assumed in the analysis of these circuits. When a battery is used the problem is probably trivial but domestic high quality amplifiers will almost invariably be operated from the supply mains. This implies that the final capacitor of the smoothing system will become the return path for the load current, an effect which is even more obvious in the usual single capacitance form of Fig. 2c. A very simple calculation indicates that the capacitance will be at least  $1,000\mu\text{F}$  and possibly  $10,000\mu\text{F}$ . This indicates that an electrolytic capacitor must be used. The problem is now to discover what type of electrolytic capacitor will operate satisfactorily when passing several ampères of audio frequency current. There are, no doubt, such capacitors available. We have had 15 ampère transistors for some time now, and 25 ampère ones are not particularly new. It is inconceivable that the use of these transistors is to be limited by a

concerted indifference on the part of the capacitor manufacturers. The engineer may well find that the solution of this problem is, however, the most difficult part in achieving the embodiment of his design.

The four transistor circuit does not avoid the need to draw a frequency doubled current from the supply. For high powers it gives us the freedom to supply the transistors with their full working current from their limiting voltage. It may be a disadvantage of this circuit that the push-pull output need not be free from a push-push component, because in deriving a feedback signal we will normally require the feedback in unbalanced form and we must make a balanced-unbalanced transformation without allowing the push-push signal to break through. It will be noted that very good suppression of the push-push signal is really desirable, for any push-push signal is likely to have a very high harmonic content if we are taking advantage of the freedom we are allowed to leave the balance between the  $Z_1, Z_2$  pair and the  $Z_3, Z_4$  pair out of our design. If we feed this distortion back to the beginning we shall construct a balancing distortion term in the push-pull signal.

For the sake of completeness we may draw two more circuits, the circuits shown in Fig. 3. The single transistor circuit will easily be recognized as a conventional amplifier circuit with choke-capacitor coupling to the load, while the second circuit is virtually the same but with the feature of two transistors in series. Since the load and the supply are no longer conjugate arms of the bridge there must be no even harmonics appearing in the supply line. The zeroth harmonics must therefore also be eliminated and we have the not surprising result that the transistors must be operated in class-A.

It would appear that the diagram of Fig. 1 covers all the structures which are used in amplifier construction so that we can turn our attention to the ways in which the transistors themselves are connected in the bridge arms. Having done this we shall also find it necessary to consider the limitations of the various methods of driving the power transistors. This is an area in which undue attention to one aspect of performance can lead to a great deal of difficulty with another. No great truths will be revealed but it is possible that some false assumptions may be exposed.



# Analysis of the Bootstrap Follower

DISCUSSION AND EXTENSION OF RECENT WORK

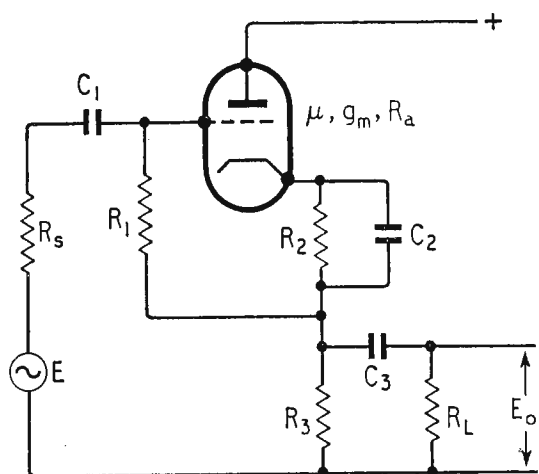
By F. BUTLER, O.B.E., B.Sc., M.I.E.E., M.Br it.I.R.E

SEVERAL recent papers have been concerned with the characteristics and applications of bootstrap amplifiers. G. W. Short<sup>1</sup> analysed the circuit shown in Fig. 1(a) in terms of its a.c. equivalent, Fig. 1(b). He derived expressions for the input impedance, output impedance and voltage gain and went on to consider the effect on the performance of valve and circuit capacitance.

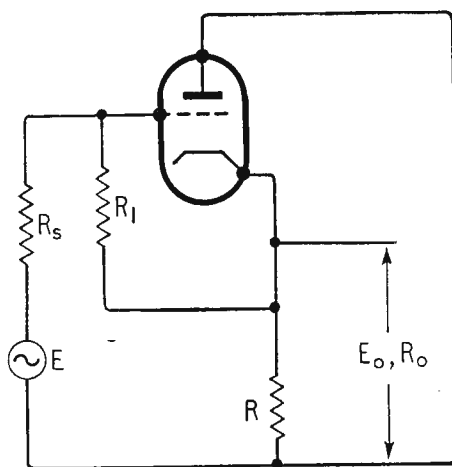
T. K. Hemingway<sup>2</sup> considered the more general circuit shown in Fig. 2(a) which has the a.c. equivalent given in Fig. 2(b). In an attempt to simplify the analysis, Hemingway assumed that the voltage gain from grid to cathode of the valve (or base to emitter of a transistor), is unity. This is unduly restrictive since some of the circuit properties depend strongly on small differences from unity gain in any practical circuit. In principle it is not difficult to make an exact analysis of Hemingway's circuit and

to derive precise expressions for the input impedance output impedance and voltage gain. Unfortunately the results are so cumbersome that it is no easy matter to translate them into a form suitable for design purposes. Nevertheless it is possible to extract a great deal of useful information from a study of special cases and the analysis is also of value because it suggests some techniques, particularly for use with transistors, by which some of the defects of the basic circuit may be eliminated. Part of the present paper is taken up with the analysis of the circuit in Fig. 2(a), making use of the equivalent shown in Fig. 2(b).

A paper by W. D. Roehr<sup>3</sup> dealt with a bootstrapped transistor amplifier and gave measurements to show how the input impedance can be made very much greater than the physical resistance connected between base and emitter. He derived an expression for the



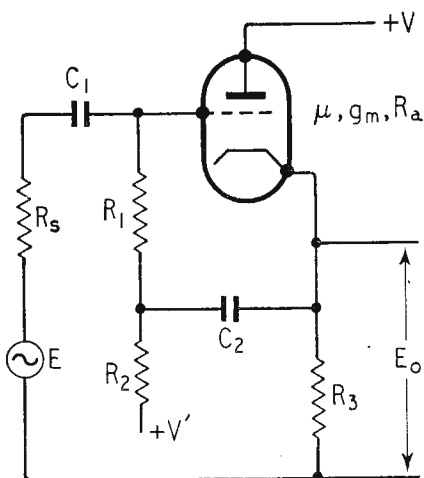
(a)



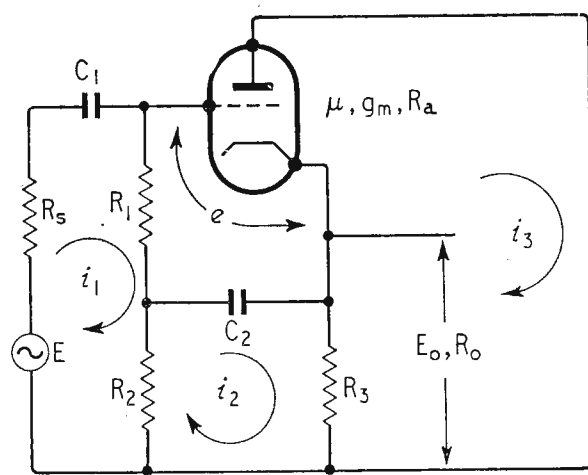
(b)

Left: Fig. 1 (a). Circuit discussed by G. W. Short and (b) its a.c. equivalent.

Right: Fig. 2. (a) Circuit analysed by T. K. Hemingway, and (b) its a.c. equivalent.



(a)



(b)

input impedance but did not calculate the voltage gain although his work can be extended to give this figure and also the output impedance.

The bootstrap principle is most commonly applied to a cathode follower or emitter follower but it may be employed with other types of amplifier. One such arrangement has been used by H. Fristoe<sup>4</sup> in the first stage of a pre-amplifier designed for use with a magnetic pickup. This present paper concludes with a description of a number of bootstrapped transistor circuits having a wide range of application. Some are believed to be new.

**Theory of the Bootstrap Follower:**—Referring to Fig. 2(b), assume that the amplifier input  $E$  causes loop currents  $i_1$ ,  $i_2$  and  $i_3$  in the network, develops an output  $E_o$  across  $R_3$  and sets up a grid-cathode voltage  $e$  in the valve. The valve itself may be replaced by an equivalent generator  $-\mu e$  having an internal resistance  $R_a$ . The signal source resistance is  $R_s$  and the internal output resistance of the amplifier is  $R_0$ .

Kirchhoff's equations for the various loops give:—

$$E = i_1 \left( R_s + R_1 + \frac{1}{j\omega C_1} \right) + i_1 R_2 - i_2 R_2 \quad (1)$$

$$-\mu e = i_3 R_a + i_3 R_3 - i_2 R_3 \quad \dots \quad (2)$$

$$e = i_1 R_1 + \frac{i_2}{j\omega C_2} \quad \dots \quad (3)$$

$$0 = (i_2 - i_1) R_2 + \frac{i_2}{j\omega C_2} + (i_2 - i_3) R_3 \quad \dots \quad (4)$$

$$-E_o = (i_3 - i_2) R_3 \quad \dots \quad (5)$$

By elimination of the three currents, an expression can be derived for the voltage gain  $E_o/E$  in terms of the valve characteristics and circuit constants. The result is:—

$$\frac{E_o}{E} = \frac{\mu R_1 + R_a + \mu \left( 1 + \frac{R_1}{R_2} \right) \frac{1}{j\omega C_2}}{\frac{1}{R_2} \left( R_s + R_1 + R_2 + \frac{1}{j\omega C_1} \right) \left\{ \mu R_1 + R_a + \mu \left( 1 + \frac{R_1}{R_2} \right) \frac{1}{j\omega C_2} \right\} + \left( 1 + \frac{R_a - \mu R_1}{R_3} \right) \left\{ \left( R_s + R_1 + R_2 + \frac{1}{j\omega C_1} \right) \left( R_2 + \frac{1}{j\omega C_2} \right) \frac{1}{R_2} - R_2 \right\}} \quad (6)$$

On separating out the real and imaginary parts of this expression it can be reduced to the form  $E_o/E = A + jB$ , from which the amplifier gain and phase shift may be determined. The result is so complicated as to be almost valueless for practical purposes and, in what follows, some special cases only will be considered.

A drastic simplification is possible if the reactances of the two coupling capacitors are negligibly small. Setting  $C_1 = C_2 = \infty$  in eqn. (6), the gain becomes:—

$$\frac{E_o}{E} = \frac{\mu R_1 + R_a}{(\mu R_1 + R_a)(R_s + R_1 + R_2) \frac{1}{R_2} + (R_s + R_1) \left( 1 + \frac{R_a - \mu R_1}{R_3} \right)} \quad \dots \quad (7)$$

By setting  $R_2 = \infty$  in eqn. (7) we arrive at the case analysed by Short. The voltage gain becomes:—

$$\frac{E_o}{E} = \frac{\mu R_1 + R_a}{\mu R_1 + R_a + (R_s + R_1) \left( 1 + \frac{R_a}{R_3} \right)} \quad \dots \quad (8)$$

This differs from Short's result, according to which the voltage gain sinks to zero if  $R_1 = 0$ , even if the signal source impedance is also zero.

Under these conditions the signal source is directly coupled to the load and the valve is inoperative as an amplifier, the load power being supplied directly from the signal generator. Setting  $R_1 = R_s = 0$  in eqn. (8) it will be seen that the voltage gain becomes unity, as it should.

Eqn. (8) may be written in a slightly different form to bring out another feature which results from the presence of  $R_1$ . The new form is:—

$$\frac{E_o}{E} = \mu + \frac{R_a}{R_1} / \mu + \frac{R_a}{R_1} + \left( 1 + \frac{R_s}{R_1} \right) \left( 1 + \frac{R_a}{R_3} \right) = \frac{\mu'}{\mu' + \left( 1 + \frac{R_s}{R_1} \right) \left( 1 + \frac{R_a}{R_3} \right)}, \quad \dots \quad (9)$$

where  $\mu' = \mu + \frac{R_a}{R_1}$ .

It appears that a reduction in  $R_1$  is equivalent to an increase in the amplification factor of the valve. This accounts for an increased voltage gain. Unfortunately it is achieved at the expense of a reduced input impedance and in any event the gain cannot exceed unity.

By setting  $R_s = 0$ ,  $C_2 = 0$  and  $C_1 = \infty$  in eqn. (7) we arrive at the case of a normal cathode follower with a grid resistance  $R_1 + R_2$  and with a load resistance  $R_3$ .

The voltage gain becomes:—

$$\frac{E_o}{E} = \frac{\mu}{\mu + 1 + \frac{R_a}{R_3}} \quad \dots \quad (10)$$

This is the standard gain expression for a cathode follower. The limiting value of the gain is  $\frac{E_o}{E} =$

$$\frac{\mu}{\mu + 1} \quad \text{with } R_3 = \infty.$$

**Input Impedance:**—One method of measuring

the input impedance of an amplifier is to drive it from a constant-voltage source and measure the output voltage. If a resistance is then connected in series with the source voltage the output will be reduced. The input resistance is equal to that value of inserted resistance which is sufficient to halve the output voltage. Symbolically:—

$$\left\{ \frac{E_o}{E} \right\}_{R_s = 0} = 2 \left\{ \frac{E_o}{E} \right\}_{R_s = R_1}$$

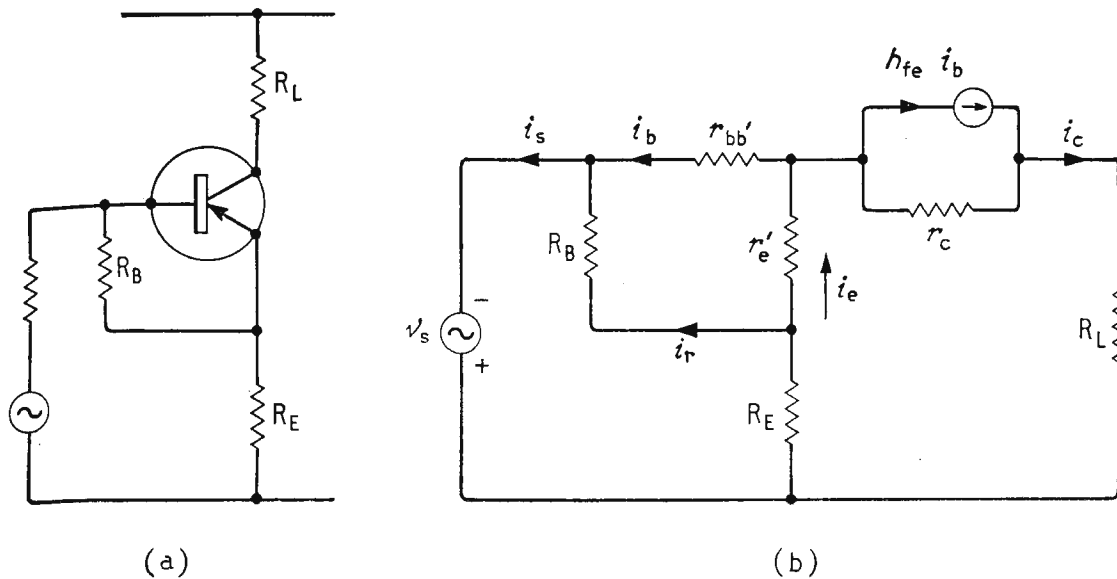


Fig. 3. (a) Circuit analysed by W. D. Roehr and (b) its a.c. equivalent.

Applying this principle to eqn. (7) the input resistance is found to be:—

$$R_i = R_1 \cdot \frac{\mu + 1 + R_a \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)}{1 + R_a \left( \frac{1}{R_2} + \frac{1}{R_3} \right)} \dots (11)$$

On setting  $R_2 = \infty$  this agrees exactly with Short's result. If  $R_2$  or  $R_3 = 0$  the input impedance becomes  $R_1$  as it should.

**Output Impedance:**—It remains to consider the output impedance of the bootstrap follower. This can be determined by a method similar in principle to that used in calculating the input impedance.

If a variable load resistance is connected across the amplifier output and adjusted so that, with constant drive, the output voltage is halved, then the output impedance must be equal to this particular value of added load resistance. Using eqn. (7), the value of the load resistance  $R_o$  which must be connected in parallel with  $R_3$  to halve the voltage gain may be calculated. The result is:—

$$R_o = \frac{R_a}{1 + \frac{\mu R_1}{R_s + R_1} + R_a \left( \frac{1}{R_s + R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)} (12)$$

With proper substitutions, this agrees with Short's calculation. His expression for  $R_o$  gives the impedance looking back into the amplifier from the load terminals and can be derived from eqn. (12) by setting  $R_2 = R_3 = \infty$ .

If  $R_s = 0$ , i.e., the amplifier is driven from a constant-voltage source, the output impedance becomes:—

$$R_o = \frac{R_a}{\mu + 1 + R_a \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)} \dots (13)$$

This corresponds to the output impedance of a cathode follower in which the load resistance is the parallel combination of  $R_1$ ,  $R_2$  and  $R_3$  and is the impedance which would be seen from the terminals of an external load resistance  $R_L$  coupled to the output of the amplifier.

If  $R_1 = R_2 = R_3 = \infty$  and  $R_s = 0$ , the output resistance is  $R_o = R_a / (\mu + 1)$ , exactly as for a cathode follower with an infinite load resistance. Finally, when  $R_2 = R_3 = R_s = \infty$ , then  $R_o = R_a$

regardless of the value of  $R_1$ , provided only that it is finite.

At this point it may be of interest to mention some rather odd properties of a bootstrap amplifier in which the circuit elements are so proportioned that  $\mu R_1 / R_2 = 1 + R_a / R_3$ . If this particular substitution is made in eqn. (6), it reduces to  $E_o / E = R_2 / (R_s + R_1 + R_2 + 1/j\omega C_1)$ . This is independent of  $C_2$  which may be removed, varied or short-circuited at will, without affecting the performance. When, additionally,  $C_1 = \infty$  the gain becomes  $R_2 / (R_s + R_1 + R_2)$  and if  $R_s = 0$ ,  $E_o / E = R_2 / (R_1 + R_2)$ .

If the same substitution is made in eqns. (11) and (12) it will be found that the input impedance becomes  $R_i = R_1 + R_2$  while the output impedance

$$\text{reduces to } R_o = \frac{1}{1 + \frac{\mu R_1}{R_a}} \cdot \frac{1}{\frac{1}{R_s + R_1} + \frac{1}{R_2}}$$

If  $R_s = 0$  and  $\mu R_1 / R_a = g_m R_1 \gg 1$ , the output impedance becomes

$$R_o = \frac{1}{g_m} \cdot \frac{R_2}{R_1 + R_2}$$

**Transistor Bootstrap Circuits:** An exact analysis of the transistor bootstrap follower is extremely tedious but the essential features are brought out in a simplified treatment due to W. D. Roehr<sup>3</sup>. He considers the circuit shown in Fig. 3(a) and

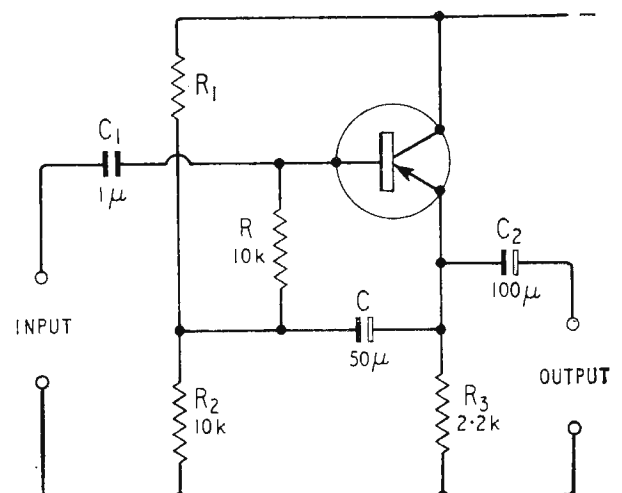


Fig. 4. Transistor bootstrap follower.

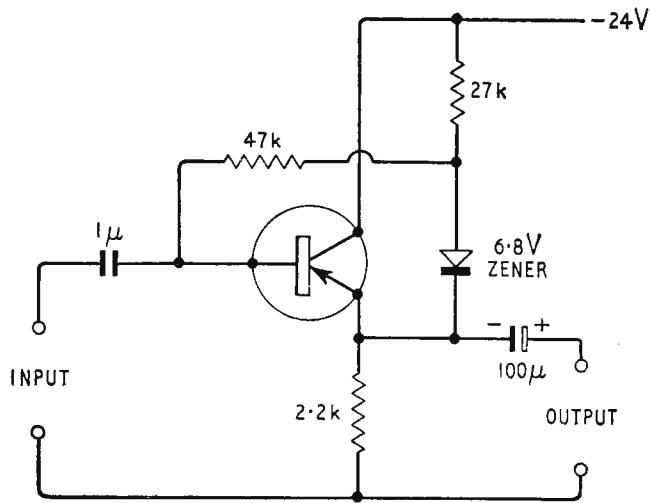


Fig. 5. Variant of Fig. 4 using Zener diode.

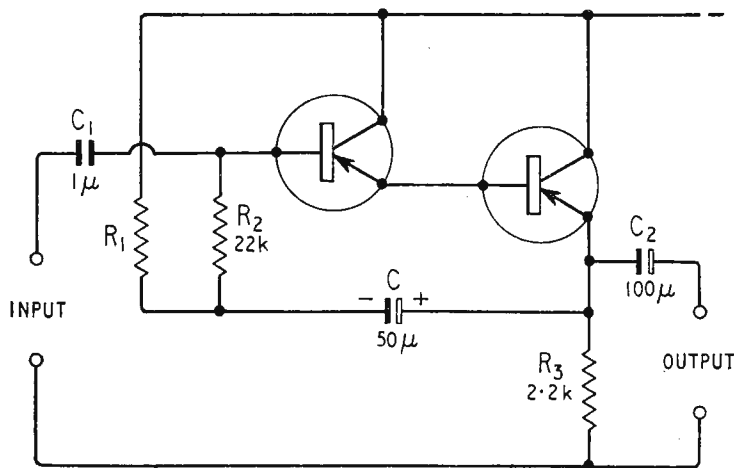


Fig. 6. Compound-connected transistors in a bootstrap amplifier.

arrives at an expression for the input impedance from a study of the equivalent circuit in Fig. 3(b). His results can be extended to give the voltage gain and output impedance and expressions for these are given below.  $R_L$  is assumed to be zero and the output voltage is measured across  $R_E$ . The amplifier is assumed to be driven from a constant-voltage source and the effect of  $r_c$  is ignored. Under these conditions:—

$$R_{in} = R_E \cdot \frac{h_{fe} + 1 + h_{ie} \left( \frac{1}{R_E} + \frac{1}{R_B} \right)}{1 + \frac{h_{ie}}{R_B}} \dots \dots (14)$$

$$R_o = \frac{h_{ie}}{h_{fe} + 1 + \frac{h_{ie}}{R_B}} \dots \dots (15)$$

$$\frac{E_o}{E} = \text{voltage gain} = \frac{E_o}{V_s} = \frac{h_{fe} + 1 + \frac{h_{ie}}{R_B}}{h_{fe} + 1 + h_{ie} \left( \frac{1}{R_B} + \frac{1}{R_E} \right)} \dots \dots (16)$$

In these three equations,  $h_{ie}$  is the input impedance of a common-emitter transistor amplifier in which the collector load is zero. It is given by  $h_{ie} =$

$(h_{fe} + 1)r'_e + r_{bb'}$ . When the signal source has an internal resistance  $R_s$ , all three expressions assume different values. For example,  $R_{in}$  clearly becomes  $R_{in} + R_s$ . The new voltage gain becomes

$$\frac{E_o}{E} \cdot \frac{R_{in}}{(R_{in} + R_s)}$$

Using these modified values, another expression can be derived for the output impedance, taking into account the finite resistance of the signal source.

After some algebraic manipulation the new equations for input impedance, output impedance and voltage gain become respectively:—

$$R'_{in} = R_s + R_E \cdot \frac{h_{fe} + 1 + h_{ie} \left( \frac{1}{R_B} + \frac{1}{R_E} \right)}{1 + \frac{h_{ie}}{R_B}} \dots \dots (17)$$

$$R'_o = \frac{h_{ie} + R_s \left( 1 + \frac{h_{ie}}{R_B} \right)}{h_{fe} + 1 + \frac{h_{ie}}{R_B}} \dots \dots (18)$$

$$\left( \frac{E_o}{E} \right)' = \frac{h_{fe} + 1 + \frac{h_{ie}}{R_B}}{h_{fe} + 1 + \frac{h_{ie}}{R_B} + \frac{1}{R_E} \left( R_s + h_{ie} + h_{ie} \frac{R_s}{R_B} \right)} \dots \dots (19)$$

As a check on the accuracy of these expressions it can be seen that they revert respectively to eqns. (14), (15) and (16) on setting  $R_s = 0$ . The input impedance is seen to depend on the load impedance while the output impedance depends on the signal source resistance. With an infinite load resistance, ( $R_E = \infty$ ), the voltage gain is of course independent of the source resistance. Other special cases give satisfactory checks; e.g., if  $R_B = 0$  the voltage gain becomes  $R_E / (R_s + R_E)$  as it should, assuming  $r_c$  to be infinite. In practice, the bootstrap amplifier will be required to supply power to a load or to drive a subsequent amplifier stage which may have a relatively low input impedance. In such cases, eqns. (17), (18) and (19) must make allowance for this. If the external load resistance coupled to the amplifier is  $R_L$  the effective total load will correspond to the parallel combination of  $R_L$  and  $R_E$ . If  $R$

is the equivalent resistance, then  $\frac{1}{R} = \frac{1}{R_E} + \frac{1}{R_L}$ . This value of  $R$  must be used instead of  $R_E$  in

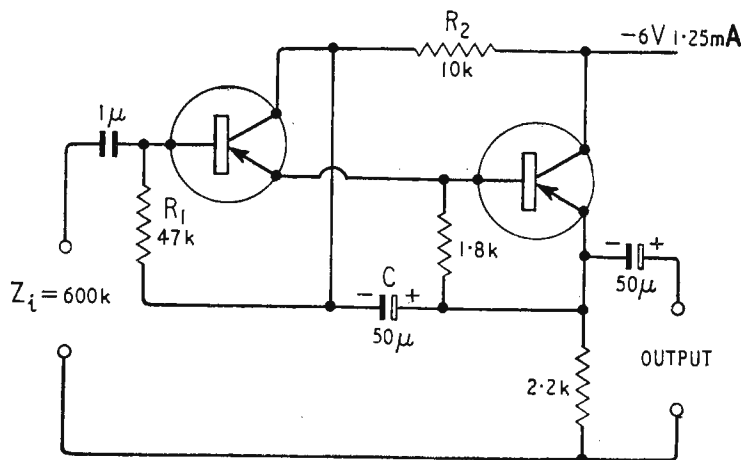


Fig. 7. Variant of Fig. 6.

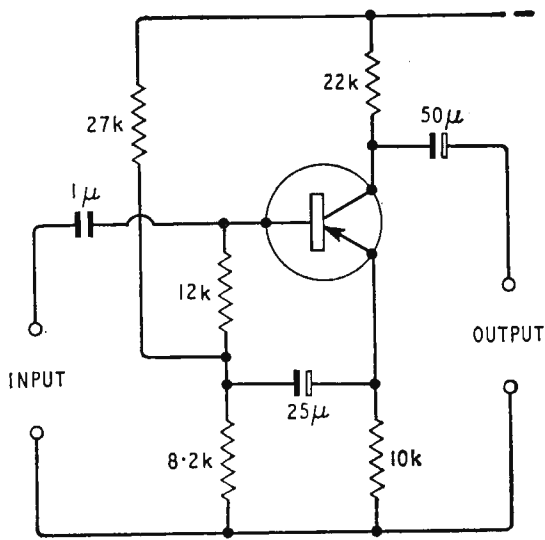


Fig. 8. Bootstrap principle applied to common-emitter amplifier.

eqns. (17) and (19). The lower effective load resistance implies a reduction of input impedance and voltage gain. Eqn. (18) also calls for some comment. As it stands, it gives the output impedance looking back into the amplifier from the terminals of  $R_E$ . When an external load  $R_L$  is connected, the impedance looking towards the amplifier must now include  $R_E$  so that the effective output impedance seen by  $R_L$  is  $R_E$  in parallel with  $R_o$  as given by eqn. (18). This equation also shows that the output impedance becomes infinite when  $R_s = \infty$ . From the viewpoint of an external load  $R_L$ , the output impedance is in fact  $R_E$  when  $R_s$  is infinite. It should also be remembered that  $r_c$ , the collector resistance, has been ignored in order to simplify the analysis. Even when  $R_s$ ,  $R_E$  and  $R_L$  are all infinite the output impedance never becomes infinite but reaches the limiting value  $r_c$ .

**Some Practical Transistor Circuits.** One of the simplest bootstrap circuits is shown in Fig. 4, with typical component values. Base bias is provided by  $R_1$  and  $R_2$ ;  $R_1$  should be varied until the resulting emitter current develops a voltage across the load resistance  $R_s$  equal to about half the supply voltage. The impedance-multiplying property of the circuit is such that the apparent resistance of  $R$  is much larger than its physical value. If the circuit is not required to function over wide ranges of temperature,  $R_2$  may be omitted and base bias supplied through  $R$  and  $R_1$  in series.

In Fig. 5, base bias is derived from the voltage drop across a suitable Zener diode and is applied to the transistor through a  $47k\Omega$  resistance. When conducting, a Zener diode has a very low a.c. impedance and virtually couples one end of the  $47k\Omega$  resistance to the transistor emitter which is one output terminal. In using this circuit, the output voltage must be restricted in amplitude or there is some risk that the diode will be cut off during a part of the cycle of the input voltage and gross distortion will result. Otherwise the arrangement is simple and effective.

Fig. 6 shows a compound-connected pair of transistors arranged to give a very high input impedance. Here again,  $R_1$  is adjusted so that about half the supply voltage is dropped across the load resistance  $R_s$ .

With base bias supplied normally from h.t.—

through a single resistance, the circuit of Fig. 7 is sometimes used when a very high input impedance is required. The bootstrap arrangement using  $R_1$ ,  $R_2$  and  $C$  causes a further rise in this impedance.

Fig. 8 shows the bootstrap principle applied to a common-emitter amplifier. In this form it has been used<sup>4</sup> as the first stage of a multi-stage pre-amplifier-equalizer. A useful increase of input impedance is achieved and the circuit proves to be ideally suited for use with a magnetic pickup.

Pairs of complementary transistors have been used extensively in an attempt to improve the performance of the common collector circuit or to produce a feedback amplifier having greater than unity gain. A bootstrapped version of one such amplifier<sup>6</sup> is given in Fig. 9. The inherent gain can be shown to be very nearly  $1 + R_4/R_3$  while the input impedance is approximately  $\beta_1\beta_2R_3$ . After designing the circuit so that the gain is slightly greater than unity the input impedance can be made very large indeed by using the bootstrap connection. Excessive gain will cause instability.

**High-frequency Performance:—**In most of the circuits described the collector-to-base capacitance of the first transistor is shunted directly across the input signal. The input current from a high-impedance source will divide equally between the amplifier input proper and the shunt capacitance

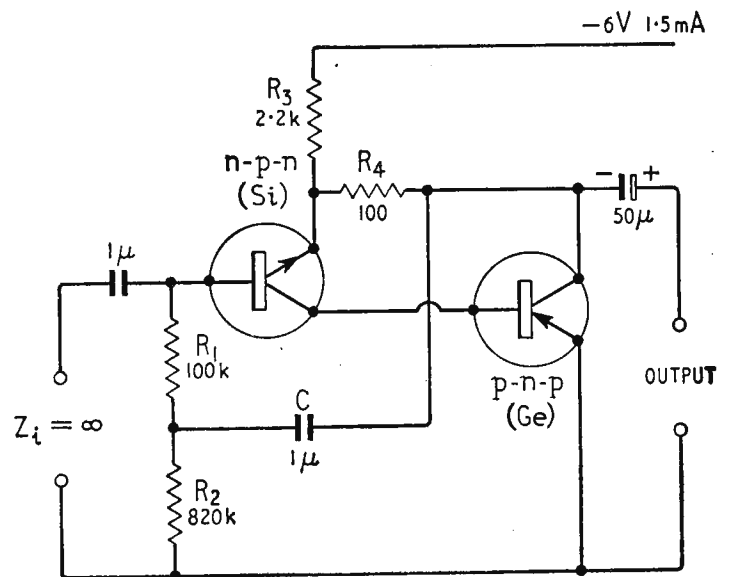


Fig. 9. Bootstrap amplifier using complementary transistors. (Component values chosen to give infinite input impedance.)

when the reactance of the latter is equal to the input resistance. There will be a 3-dB drop in gain at this critical frequency. Matters are worst in circuits designed for a very high input impedance. One remedy is to drive the amplifier from a constant-voltage low-impedance source. Another is to apply some form of equalization or to use v.h.f. transistors with very low collector-to-base capacitance. In practice it is not difficult to get a uniform response up to 50 or 100 kc/s while maintaining a reasonably high input impedance, even when operating with a high-impedance signal source.

**Noise Figures:—**Transistor noise is often troublesome in amplifiers which are operated from high-impedance sources. Recent work shows that when low noise figures are important it is desirable to use

silicon planar epitaxial transistors. The price of these has recently dropped to an economical figure and their characteristics are not much degraded by high-temperature or low-current operation. High-frequency types should be selected for use in wide-band amplifiers using bootstrap techniques.

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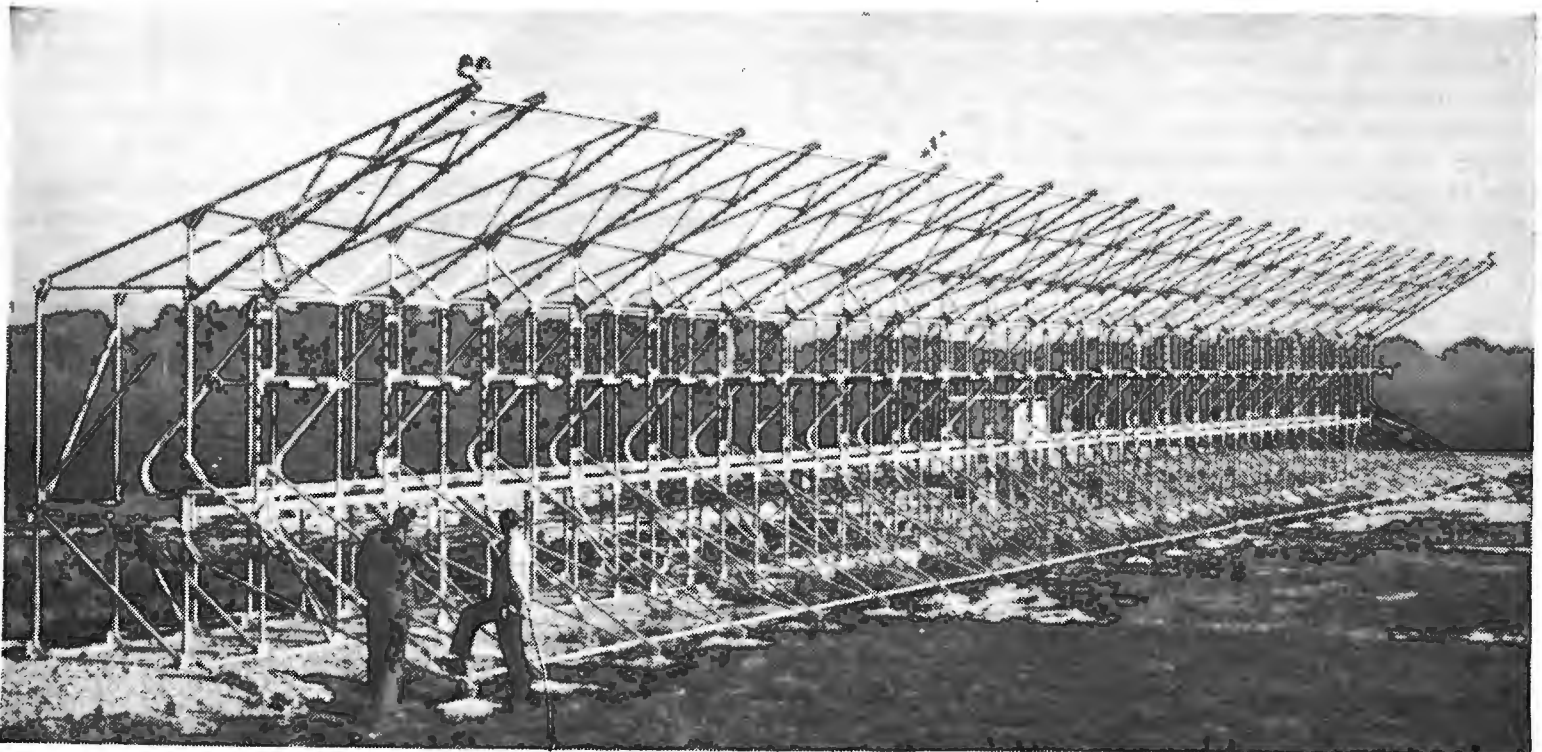
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## WIDE-APERTURE AERIAL FOR INSTRUMENT LANDING

DESIGNED to fulfil the automatic landing requirements of the International Civil Aviation Organization's Category Three, a new 160-ft long i.l.s. (instrument landing system) aerial developed by Standard Telephones and Cables has been installed at Hurn Airport for trials. The aerial is fed by a STAN 7 localizer transmitter and radiates a 4° beam centred on the runway centre-line. This extremely narrow beam, which is needed to avoid illuminating reflecting objects and distorting the approach path, is obtained by placing 24 horizontal dipoles in front of a wire-mesh reflector. Reflections from overflying aircraft are eliminated by a wire-mesh horn. Signals to the dipoles are graded in power, so that two differently modulated beams diverge slightly, overlapping along the runway. The modulation of each beam corresponds to "fly left" and "fly right" information, and when the signals at the aircraft receiver output are equal in amplitude, the aircraft is on the runway centre-line. The outputs are visual (for manual landing) or electrical (for autopilot operation).

I.C.A.O. Category Three requires full guidance from 25 nautical miles range to touch down and roll along the runway, and in trials the S.T.C. system has satisfied these requirements in azimuth. Previous systems have been too inaccurate for guidance to touch down, and magnetic leader cables have been employed, with an associated receiver in the aircraft. STAN 7., with the new aerial, is now a rival to this method, and one receiver can provide full azimuth guidance. No clearance pattern for "capturing" the aircraft is radiated, and guidance within range of STAN 7 is provided by either normal ground radar, or by a terminal VOR beacon.

Although its application to automatic landing is obvious, the system is perfectly usable by manually controlled aircraft, and is, in fact, used in many U.K., European and Canadian airports. The new aerial provides an accuracy sufficient to enable an aircraft to take off using i.l.s., although this is in the nature of a bonus of the system.



S.T.C. instrument landing aerial. If struck by over-shooting aircraft, whole structure is designed to collapse with a minimum of damage to the aircraft.

# LETTERS TO THE EDITOR

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

## New Phase Splitter

IN his article in the September issue, Mr. Bailey states that an important attribute for a phase splitter is that the output impedances, as measured between each output and earth, should be equal. He implies that if this requirement is not satisfied, then (a) severe grid blocking can occur if the amplifier is accidentally overdriven, and (b) the phase splitter output voltages will become badly unbalanced at high frequencies owing to the different time constants present. He then criticizes the floating paraphase and concertina phase splitters in the above context. I consider that his criticisms are unjustified and based on incorrect reasoning.

First, grid blocking will inevitably occur on heavy overloading, if the usual R-C coupling to the output valves is used, *no matter whether the output impedances at the two outputs of the phase-splitter are equal or not.* The cure is simply to avoid excessive overloads!

Secondly, and as pointed out by Mr. Williams in his letter in the November issue, even though the output impedances, measured separately between each output point and earth, are admittedly quite unequal with the concertina circuit, it does *not* follow from this that, with equal stray capacitance loads *simultaneously* present on these two outputs, the outputs will become unbalanced in amplitude or phase at high frequencies.

The vital point is that any capacitance load thrown on the cathode output will cause the valve to turn on extra current at high frequencies, this extra current, which flows in the anode as well as the cathode lead, being just that required (assuming equal capacitance loadings) to maintain the anode output equal to that from the cathode.

Mr. Williams makes a slip, however, when he calculates the "break-point" frequencies, or "corner" frequencies as I would call them. The answer he gives would be correct if the input voltage to the phase splitter were applied between grid and cathode and if the valve had infinite a.c. resistance. With the input voltage applied between grid and earth, however, there is a large amount of negative feedback, as in a cathode follower, and this greatly improves the frequency response.

With equal anode and cathode loads  $R_L$ , and equal capacitances  $C$  to earth from anode and cathode, the corner frequencies at both outputs in fact correspond to the reactance of  $C$  being approximately equal to  $1/g_m$ . Thus with  $C=20$  pF, even if  $g_m$  is as low as 1 mA/V, this gives a corner frequency of 8 Mc/s, i.e. the response is -3 dB at this frequency. Even at this frequency, however, the two outputs remain, in simple theory, equal in magnitude and accurately in antiphase. This result would apply in practice, were it not for the presence of the valve capacitances  $C_{a-g}$  and  $C_{g-k}$ , which I have so far ignored.

The detailed theory of the concertina phase splitter, including the effects of valve capacitances, is presented with excellent thoroughness in an article in *Electronic and Radio Engineer*, July 1959, p. 271. It is there concluded that, with typical values as used in practical designs:—

(a) Amplitude and phase unbalance are quite negligible up to 20 kc/s, e.g. 0.5% and  $2^\circ$ .

(b) At higher frequencies valve capacitances cause a departure from the wanted  $180^\circ$  relationship, this departure, in the example given, amounting to about  $13^\circ$  at 150 kc/s.

(c) As far as the effect of the phase splitter on the feedback stability of an amplifier is concerned, what really matters is how the phase of the voltage *between* the two phase splitter output points, relative to the input phase, varies with frequency. It is this difference voltage which appears between the output valve grids. The effect of the valve capacitances is to cause the anode output to lag on its ideal phasing and the cathode output to lead, with the result that the voltage between the two output points differs in phase from the input voltage by much less than the individual outputs do. A total effective phase lag, in the typical concertina circuit analysed, of about  $8^\circ$  at 500 kc/s is deduced.

It seems appropriate to quote the last few lines of the article in *Electronic and Radio Engineer*:—

"In an a.f. negative-feedback amplifier, the inclusion of a concertina phase-splitter within the feedback loop will normally have negligible influence on the overall amplitude and phase responses at high frequencies. Its phase shift will be negligible compared with that of other stages."

Thus I do not in any way regret my choice of a direct-coupled concertina phase splitter in my 5-Watt amplifier described in *Wireless World*, March and April, 1957 (and in the booklet "Low-Cost High-Quality Amplifier"). I believe that this amplifier, used within its power rating, gives results not audibly inferior to those of the most expensive amplifiers, and I have never heard of anyone having instability troubles with it.

Great Malvern,  
Worcs.

PETER J. BAXANDALL

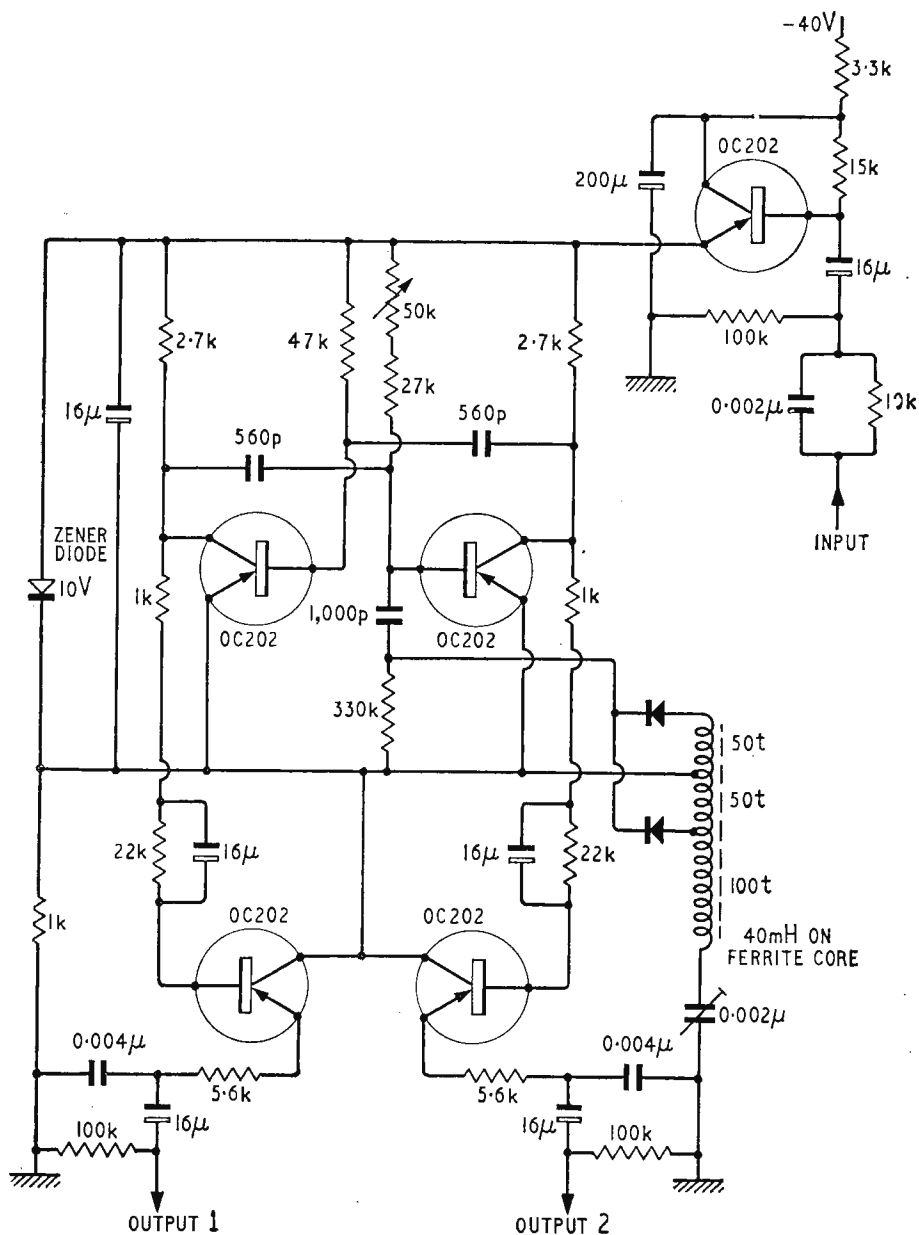
## Stereo Decoder

THIS design of a decoder for the Zenith-G.E. stereo multiplex system may be of interest; it is the result of some weeks' intermittent consideration of this problem and enrolls most desirable features with simplicity and economy.

The design consists basically of a 38kc/s multivibrator operating two symmetrical transistor switches in opposite phase to one another; the multivibrator is locked and "phased" to the 19kc/s pilot signal via a single adjustable 19kc/s LC resonant circuit.

A most fitting arrangement results from carrying the complete multivibrator on the "work line" and supplying its power by operating it in series with the input transistor interposed between the transistor itself and its load. The input transistor is fed back or emitter-follower-connected to yield a low-impedance "work line" so that it can drive a fairly high-Q 19kc/s series resonant circuit capable of producing synchronizing pulses from a low input level. Sharp pulses are generated from a full-wave rectifier arrangement in order to maintain good 50/50 38kc/s square waves accurately phased over a wide range of input levels.

The use of symmetrical transistors as a.c. switches for demodulation can hardly be bettered and offers a routine performance much better than could normally be expected from a good balanced mixer in this service. In the design as shown, normal transistors (OC202) have been used which have a "reverse" gain of only about two or three; the standing h.f. at the unit's output terminals, due entirely to switching spikes, is nevertheless only about 10mV. The design as it stands can yield



outputs up to a peak of about 3 volts and 1mA, and it consumes about 5mA from the supply. With the use of symmetrical transistors with gains around 30, the design is clearly capable of further improvement and possibly further simplification.

The unit has given excellent trouble-free performance without adjustment over a wide range of signal levels; crosstalk between channels is small (say about 30dB) when judged on the B.B.C. experimental broadcasts in conjunction with a fully transistorized surrounding system.

Maldon, Essex.

W. L. GREGORY.

## Distortion and Local Feedback

MR. G. EDWIN, in your November issue, mentions that most amplifiers incorporate internal feedback loops, e.g. cathode bias resistors left uncoupled. It is perhaps of interest to note that small amounts of feedback can worsen higher order harmonic distortion. As a typical example consider an amplifying stage operated at a low level so that the 3rd, and higher, harmonic distortion is very small and can be neglected and only the 2nd harmonic distortion need be considered. If now a small amount of feedback is applied, signals at the fundamental and second harmonic frequencies will be fed back into the input circuit and the resulting second-order intermodulation will produce sum and difference frequencies. The sum frequency corresponds with the third harmonic of the fundamental. The level of this harmonic will be reduced by the feedback, but

it can be higher than the value without feedback.

As a typical example, using a CV138 valve with a low signal level and a given output level, the third harmonic is substantially unaltered or worsened by about 3dB when 6dB or 3dB of feedback is applied, respectively. The second harmonic level is reduced by about 6dB or 3dB respectively.

Mr. G. Edwin briefly considers the operation of a feedback amplifier in an overloaded condition, but does not mention that instability can be produced. At critical input levels it has been shown\* that sustained oscillation can occur due to phase changes in the feedback loop that are produced by intermodulation.

F. G. CLIFFORD

Harrow, Middlesex.

\*F. G. Clifford. *Proc. I.E.E.* Vol. 99, Part IIIA. No. 18, 1952. Paper No. 1318. Radio Section.

*The author replies.*

The omissions mentioned by Mr. Clifford are only small examples of the material which has been excluded in order to keep the series of articles short and simple. These articles were not meant for Mr. Clifford to read. Once we embark on the less elementary aspects of amplifier design we must be careful to avoid generalization. Mr. Clifford's first paragraph is not necessarily true, for example.

The mechanism by which the 3rd harmonic is produced by mixing fundamental and 2nd harmonic, and by which the higher intermodulation terms of two tones are produced, is one way of describing the effect. Other readers may prefer to construct mutual conductance curves and to note how the cut-off bend becomes sharper. This second method is valuable in showing how small amounts of local feedback can produce a very large reduction in third harmonic if the intermodulation third and the valve-generated third are in anti-phase. This condition has been obtained by careful choice of operating conditions with the 5763 valve.

In less advanced design work the main functions of the local feedback are probably gain stabilization to avoid loop gain problems, and here the stabilization of the cathode current may play an important part; and reduction of loop gain combined with economy because the designer wants, say, 40dB overall gain and 20dB of feedback and finds that he has 70dB to play with.

Before moving up into the rather rarefied atmosphere of Mr. Clifford's last paragraph we might hope that designing would progress beyond a dozen short elementary articles. Change of loop gain due to swinging up the  $g_m$  characteristic change of loop response, due to grid current loading, the Clifford effect, and the gain reduction due to grid loading with its effect on conditionally stable amplifiers; which of these is really a topic for the beginner? The whole purpose of the series was to provide a foundation without alarming the reader; the texts available at a higher level are excellent, but, to some readers, forbidding.

G. EDWIN

## LC Oscillator Design

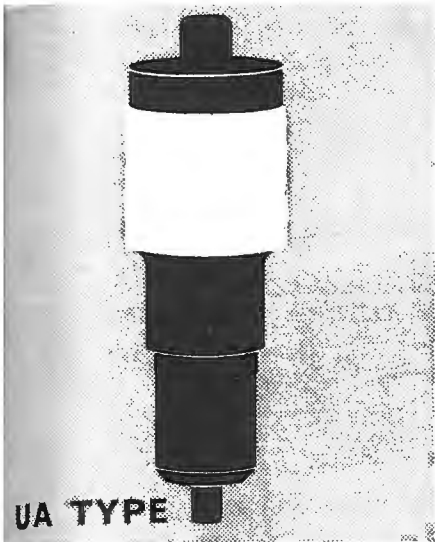
ON reading the article by R. C. Foss and M. F. Sizmur in the November issue, I was prompted to turn up a paper on "Cathode Coupled Oscillators" which I contributed to *Wireless Engineer* in November 1944. In

(Continued on page 29)



# 'ENGLISH ELECTRIC'

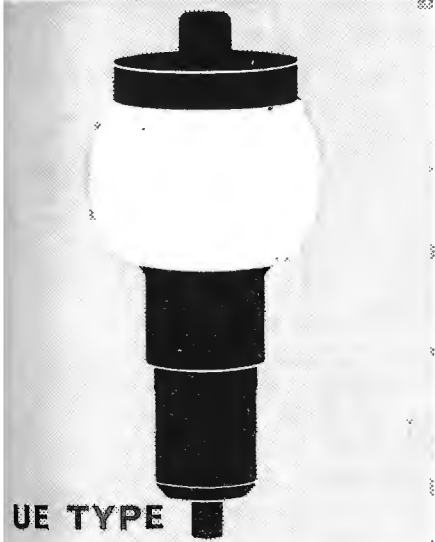
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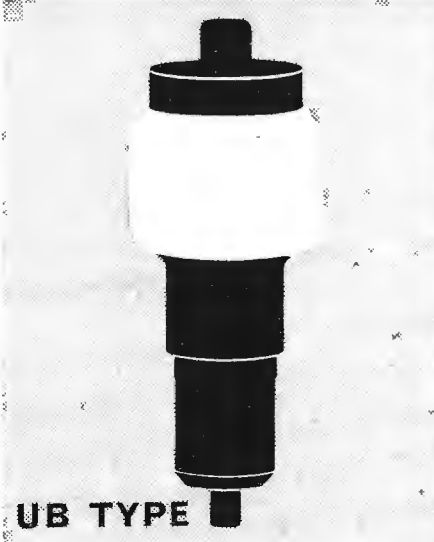
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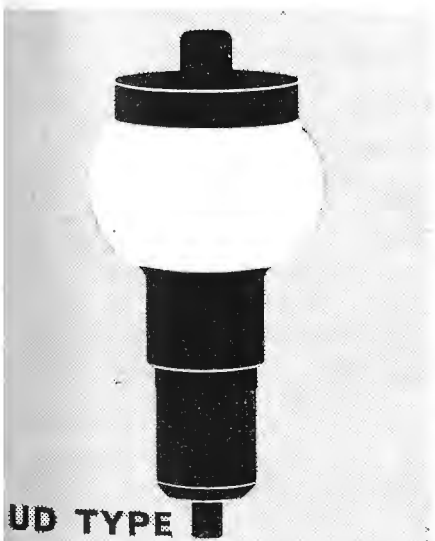
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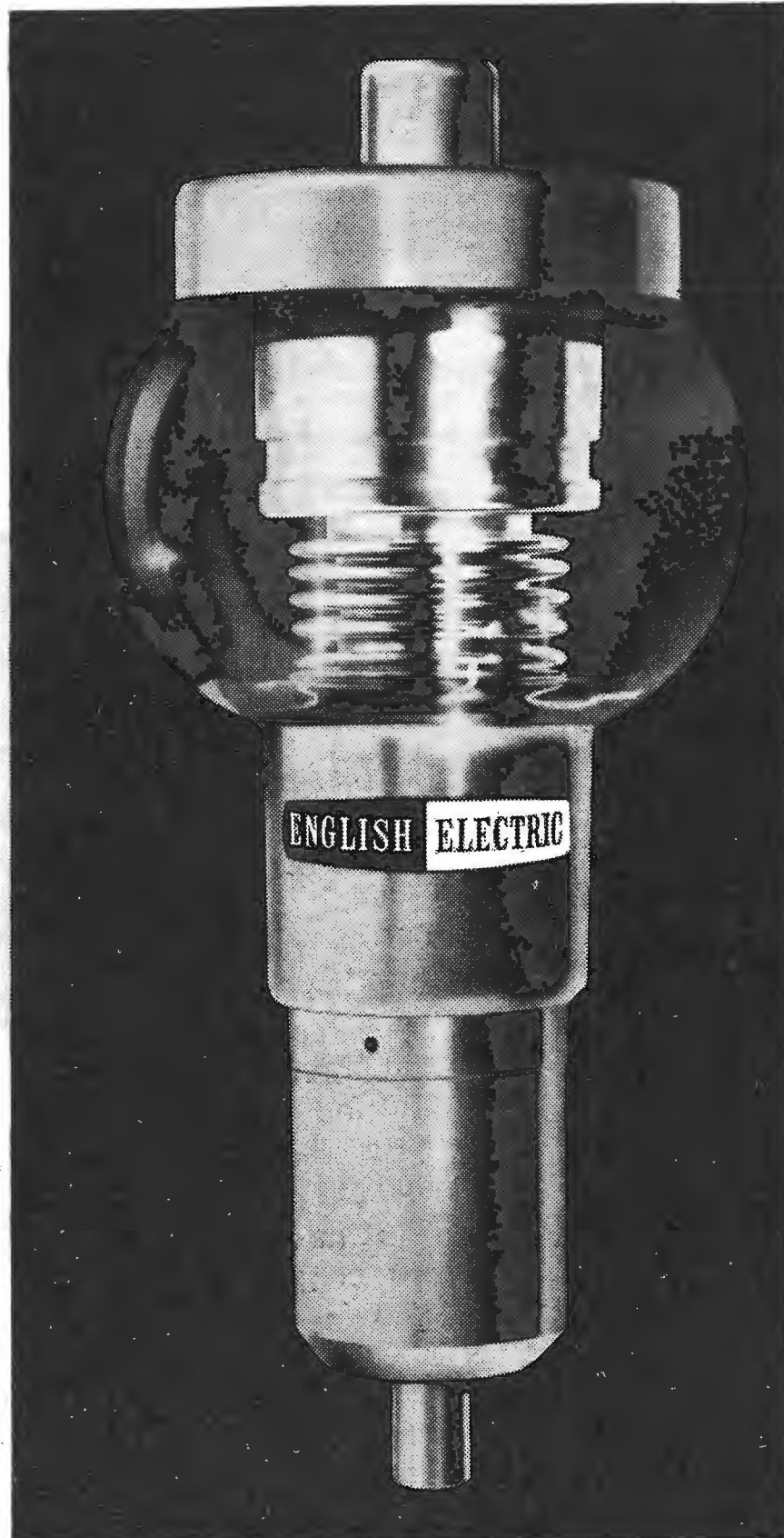
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overload



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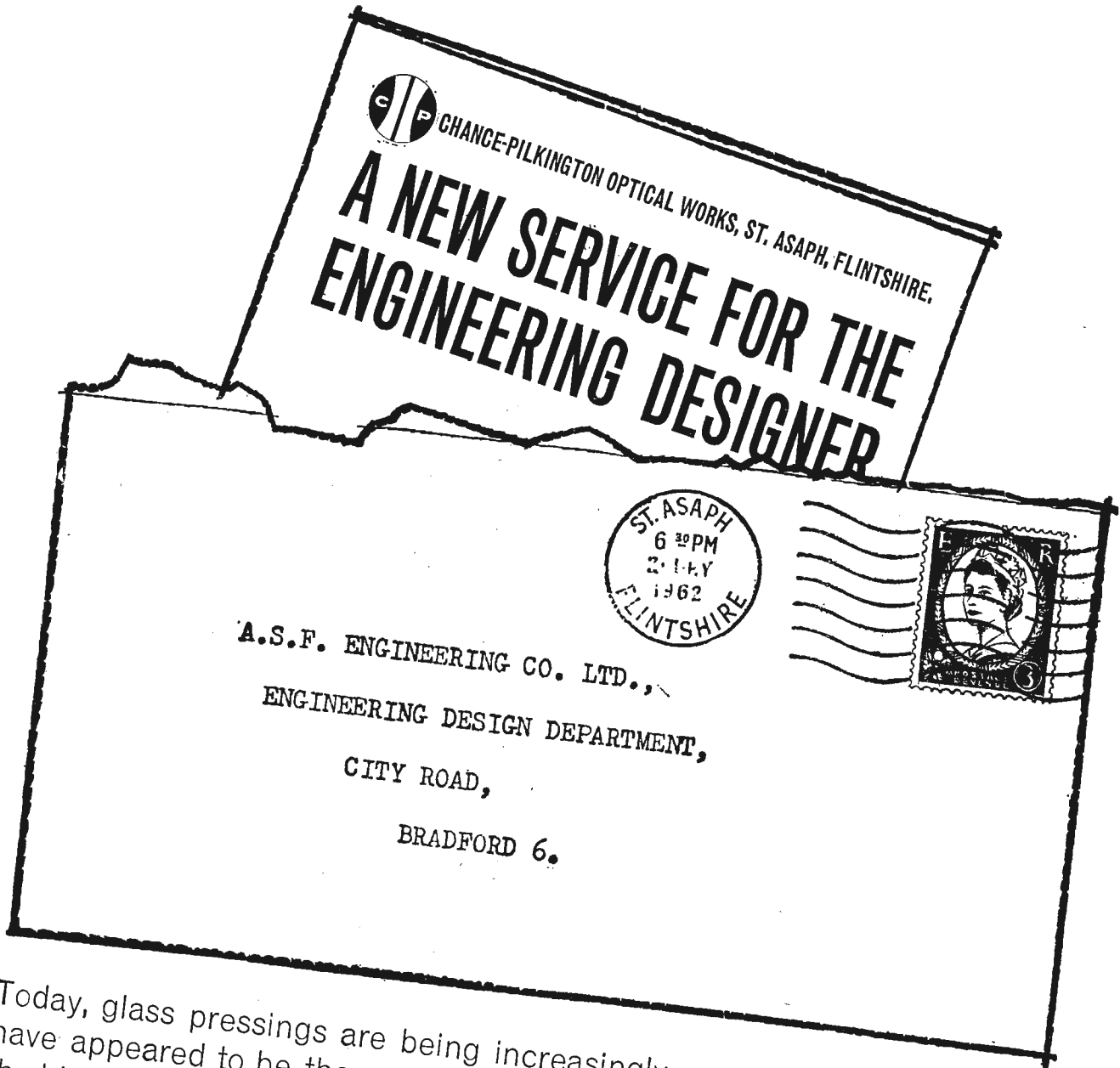


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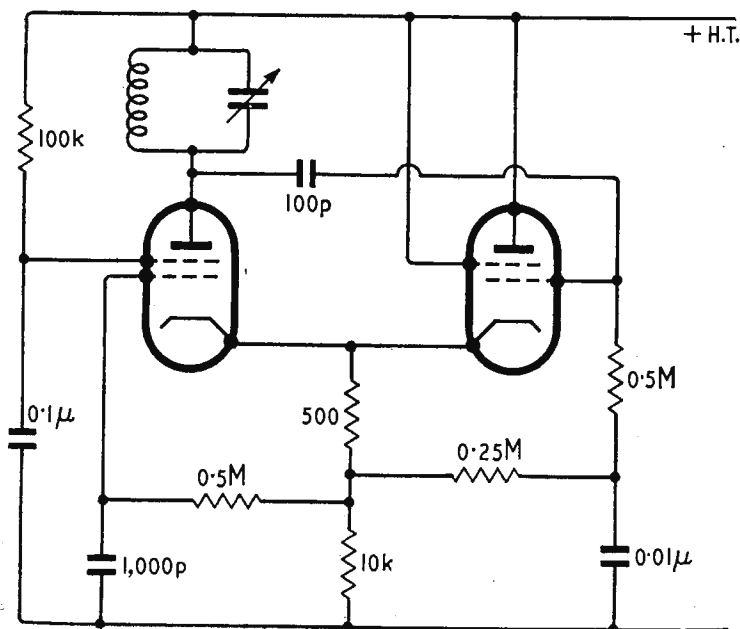
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this I gave the linear theory of cathode-coupled amplifiers and went on to treat the oscillator as an amplifier with regenerative feedback. This allowed the oscillation maintenance criteria to be derived in terms of the circuit parameters. In the interests of generality I considered dissimilar valves. With identical valves and with an infinite "tail" resistance the limiting maintenance condition reduces to  $R_d = 2/g_m$ , where  $R_d$  is the dynamic resistance of the tuned circuit and  $g_m$  is the mutual conductance of each valve.

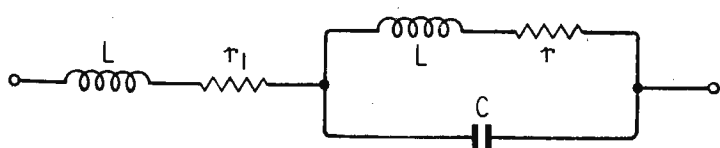
Readers interested in this subject may care to study a practical circuit which I gave (a). Superficially it has a resemblance to Fig. 3 in Foss and Sizmur's paper. Certainly it has a high-value coupling resistance, but I am not sure that it is a true long-tailed pair, because of the biasing arrangement used. I should explain that there is no particular virtue in using tetrodes instead of triodes, and in fact I have used both. Their circuit also differs from mine in that they use a separate high-voltage negative supply to the tail resistor, and this may be a crucial distinction, though I am not convinced that it is. What do they think?

I feel that they are a little severe in their strictures on the conventional oscillator. Normally this is operated under Class C conditions, in which the tuned circuit is driven by brief pulses of anode current so that variations of  $R_a$  throughout the cycle scarcely enter into the picture. In the same way, grid current is only drawn for a small fraction of the time of one cycle and is not normally troublesome unless the oscillator must feed a variable load.

The authors gloss over one important point concerning the use of transistor long-tailed pairs in a switching-type oscillator. The output capacitance of most transistors is fairly strongly dependent on the instantaneous collector-emitter potential. Switching thus has the effect of alternately connecting two discrete values of added capacitance across the tuned circuit. Presumably the input capacitance of the associated switching transistor will have similar effects. These remarks are not meant to imply that the switching technique is unsound but to point out some second-order effects which should not be ignored.



(a)



(b)

To conclude, I would like to mention a small artifice which may be used to improve the stability of certain types of LC oscillator in the face of variable resistive loading. It is well known that the resonant frequency of a parallel-tuned circuit depends on the resistance in the inductive arm, i.e. on the Q of the inductor. There are several circuit tricks which may be used to compensate for this effect. One of the best was first proposed so long ago that most people have forgotten it and some may never have heard of it. A conventional parallel-tuned circuit with a loss resistance  $r$  in series with the inductance  $L$  is shown at (b). The capacitor  $C$  is assumed to be loss free. In series with this circuit there is a compensating inductance also equal to  $L$  but with a different series resistance  $r_1$ .

The impedance of the combination can be written down by inspection, and is:—

$$Z = r_1 + j\omega L + \frac{1}{\frac{1}{r + j\omega L} + j\omega C}$$

$$= r_1 + j\omega L + \frac{r + j\omega L}{1 - \omega^2 LC + j\omega Cr}$$

On setting  $\omega^2 LC = 1$ ,

$$Z = r_1 + j\omega L + \frac{1}{j\omega C} + \frac{L}{Cr}$$

$$= r_1 + \frac{L}{Cr} = r_1 + R_d$$

where  $R_d$  is the dynamic resistance of the parallel-tuned part of the circuit.

The circuit is thus purely resistive at the frequency given by  $\omega^2 LC = 1$ , regardless of the resistances of the two coils. Clearly the resistive condition is not violated if the entire circuit is shunted by any other pure resistance, fixed or variable. The technique is particularly convenient for use with negative-resistance oscillators of the dynatron or transitron type, with tunnel diodes or with the cathode-coupled oscillator in any of its forms. A point to notice is that the two coils must be of exactly equal inductance and must be decoupled from each other. There are no restrictions on their series resistances. The self-capacitances should be small. An important point to note is that the resistive condition is not disturbed on tuning the circuit by varying  $C$ . As usual, the highest stability is achieved by making  $C$  large enough to swamp any stray or variable external parallel capacitance.

Cheltenham, Glos.

F. BUTLER

## Reduced Coverage—More Programmes

WHILE agreeing with what Mr. P. P. Eckersley has said about wired networks, and Dr. R. G. C. Williams about an electronic grid, I think it should be added that the start, let alone the completion of a significant portion of such a scheme, is many years away. It would be an irresponsible act for any Government to initiate such a project using the tried and proven techniques of today. The cost would be enormous and methods used would prove to be inadequate, cumbersome and outmoded before a fraction of the work had been completed. The art of broadband transmission is still in its developing stage. Use of long waveguide transmission systems is still under examination and development. The exploration of that part of the frequency spectrum which lies between radio frequencies and the infra-red has only just begun. It is also certain that new and elegant techniques will emerge from these and other fields of research.

However, Mr. Eckersley's demand for greater choice of programme need not wait upon the fulfilment of these schemes of widespread networks and electronic grids. There is an answer to the problem close at hand. All that is necessary is that the shibboleth of "full national coverage" should be challenged and destroyed. There are sound historical reasons why this doctrine

has been accepted up to the present; but there exist no arguments as to why it should persist into the future without question or re-examination. So long as the whole of the country obtains an adequate choice of programme, it is wasteful and extravagant of money and channels to plan to give every broadcast programme full or nearly full national coverage.

During the Commons debate on the Pilkington report, Captain Orr (M.P. for Down, South) said:—

“It is not often realized that in extending coverage over the nation the last 10 per cent or 15 per cent of the population covered requires as many frequencies as does the first 85 per cent. Therefore, in our future thinking we must be careful not to insist on national coverage, which is wasteful in money, wasteful in men and resources and wasteful in frequency, and that is even more important.”

Put in another way, if a certain number of channels are required to give a programme near national coverage, one-third of these will enable two-thirds of the population of the U.K. to be reached, and two-thirds are needed to bring the programme to the remaining third.

The argument for a size of choice graded in proportion to the density of population is one which need not be “hooked on” to the advocacy of any particular type of service; it is valid in its own right. Successful challenge of the doctrine of “full national coverage” will provide great flexibility in the use of our valuable u.h.f. channels in the future.

The protest of the egalitarians who say—“all or none”—just does not hold water in this case, any more than it does in an infinite number of other circumstances in our society today.

London, W.1.

L. S. WHITE

## 2 MT

THE transmitter from which test programmes were broadcast in February, 1922, from the Writtle establishment of Marconi's Wireless Telegraph Company Limited is frequently mentioned in correspondence and it has occurred to me that you may be interested to have an authentic description of this transmitter for the record. The information will no doubt be of interest when the 50th or 100th anniversary of broadcasting in this country is celebrated.

When the Writtle Experimental Establishment of the Marconi Company was requested to produce a transmitter there was no difficulty in design work. We simply used the standard Marconi radiotelephony transmitting circuit of those days.

At the beginning of the transmissions on the 14th February 1922, the transmitter operated on a wavelength of 700 metres with an approximate power to the aerial of 200 watts.

The aerial was of the 4-wire inverted “L” configuration, supported by two 110ft Marconi portable masts and was 140ft long.

The circuit of the transmitter is depicted in the accompanying diagram. It will be observed that the radio-frequency circuit was of the self-oscillatory variety using a reaction coil coupled to the main tank circuit, the reaction coil being tuned to 0.7 of the operating wavelength.

The aerial tuning coil consisted of an ebonite slat former wound with 243/36-stranded cable. This was magnetically coupled to a primary tuning circuit, the inductance of which was wound with 729/44-stranded wire. This inductance is shown on the left of the photograph, and is of interest because it was made under Mr. P. P. Eckersley's direction in 1919 and the stranded wire was actually made on the premises. This inductance was used initially to investigate the application of Mr. T. L. Eckersley's earth screen to medium wave aerials. The closed circuit condenser consisted of a stack of zinc plates separated by ebonite insulators. This was situated under the bench on which the inductance was mounted.

In order to obtain the correct anode impedance, a tightly coupled secondary winding, consisting of a coil of No. 20 gauge wire, was wound over the primary tuning inductance.

The circuit was shunt connected to one M.T.4 triode, which was a standard Marconi valve at the time. Amplitude modulation was effected by a Heising circuit, one M.T.4 being used as a modulator and another as an amplifier. In the first few transmissions the microphone was directly connected to the grid of this valve.

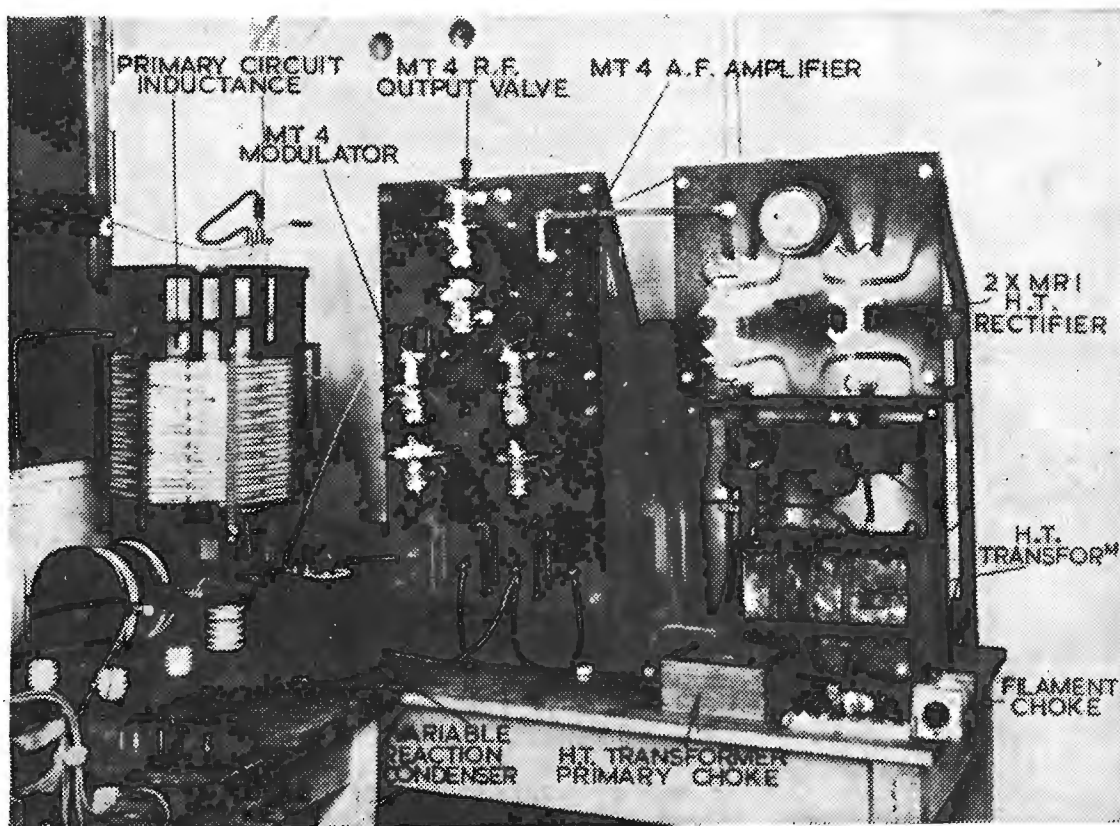
The anode high tension, at 8,000 volts, was supplied by two M.R.1 valves in bi-phase connection. The valves and high tension transformer are also shown in the photograph.

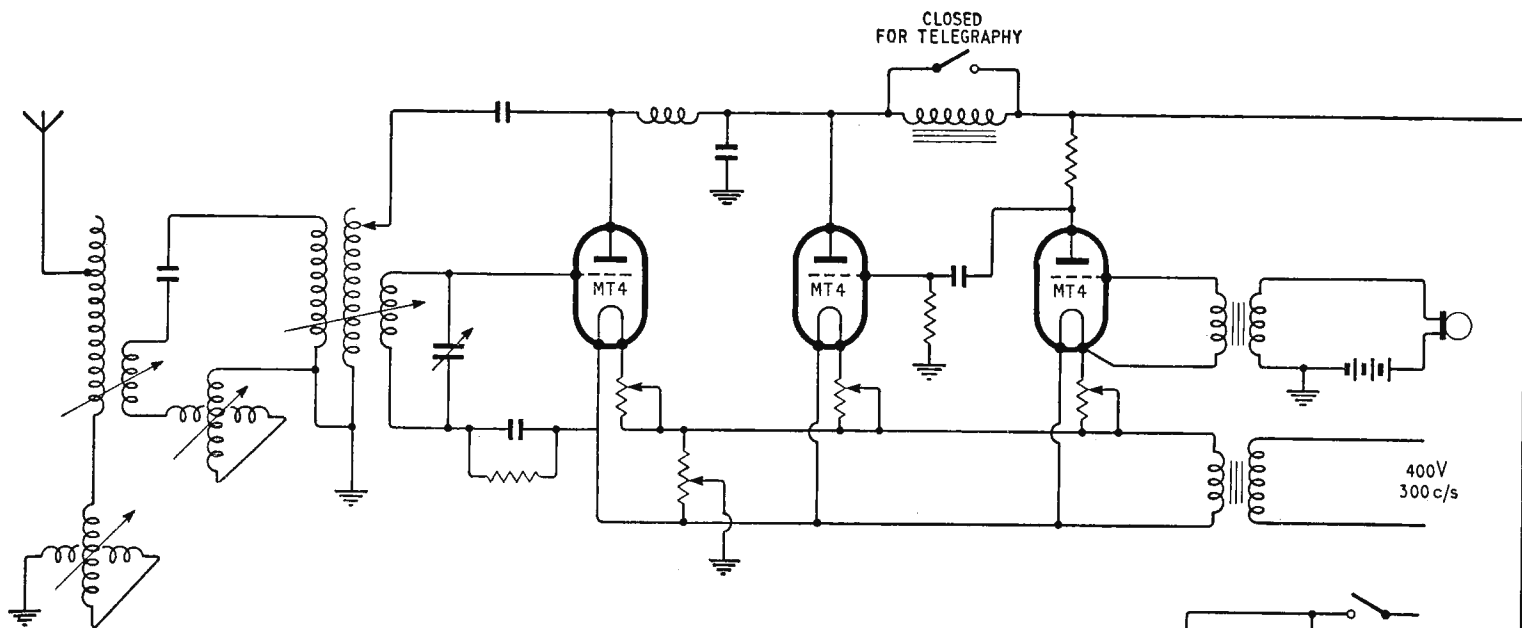
The primary supply to the h.t. transformers and the filament transformers was supplied by a 400-volt, 300 c/s, single-phase alternator, driven by a 110-volt d.c. motor which received its supply from two 4½ kW, 110-volt, petrol (4-cylinder Austins) motor generators.

For the first few months, morse was transmitted during a proportion of the programme time for the purpose of providing calibrating signals to amateurs. Keying was effected by interruption of the h.t. transformer primary circuit by a standard Marconi morse key. This key is shown in the lower left of the photograph.

The valves and other components were mounted on two panels obtained from a disused c.w. transmitter.

The circuitry was precisely similar to that designed by Mr. P. P.





Eckersley for the ground station transmitter installed at Croydon Aerodrome in 1920. The transmitter was very simple compared with others under development at Writtle at that time and, initially, it was got going within an hour.

Unfortunately, while the Heising modulation circuit was suitable for high-quality reproduction, the only valve available at the date of commencement of service was the M.T.4 which we realized would not be capable of providing reasonably good quality, even for those days.

After one or two transmissions, a microphone amplifier was used in place of the M.R.4 amplifier and three M.T.4 valves with the grids biased positive were used in an effort to obtain linear working. Unfortunately, it was not possible to obtain sufficient dissipation at the anodes of these valves to provide Class AB working. In the meantime, N. (later Sir Noel) Ashbridge and H. L. Kirke were working on the problem and devised the characteristics of suitable valves which were developed by the M.O. Valve Co. These were delivered in a remarkably short time and three were used in parallel, operating in the Class A mode.

The components from which the transmitter was built were mainly supplied from our experimental stock in trade. Any suggestion that we were wildly searching for components or struggling to make the transmitter work is simply not correct. If we were short of anything the Marconi laboratories and works at New Street, Chelmsford, supplied our wants within the hour.

The physical assembly of the transmitter was carried out by the workshop mechanics, F. Bubb and J. Russell.

The limitation was then the Peel Connor carbon microphone which was used throughout the transmissions. Unfortunately, no other type of microphone was available until Captain Round produced the Round/Sykes microphone in 1923.

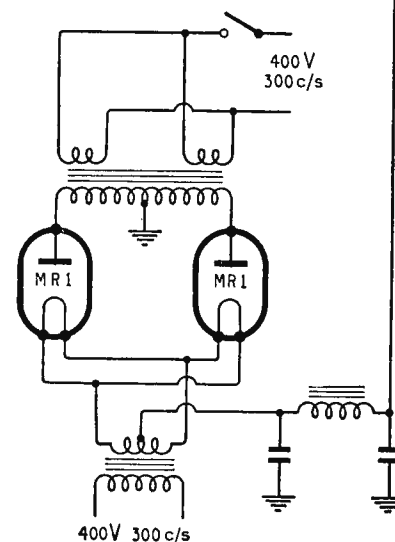
On the 29th May 1922 the wavelength was changed to 400 metres and the transmission of morse calibration signals was abandoned.

The coupled circuit was dismantled and a plain aerial circuit was adopted, using an aerial tuning inductance wound with 81/44-stranded cable. This coil was tightly coupled to a secondary winding, known as the "ratio winding" patented by Eckersley in 1919.

The transmitter circuit remained in this condition until the final transmission on the 17th January 1923.

It is unfortunate that on the cessation of transmission in January 1923 the equipment was dismantled and the parts returned for normal experimental work. All has been lost with the exception of the 6kW motor generator which the writer found under a tarpaulin in a field at Writtle a few years ago. This he purchased from the Marconi Company, dismantled, dried out

2 MT, Writtle Feb 14th 1922



and made to work. In due course it will be presented to the Marconi museum.

Chelmsford, Essex.

B. N. MACLARTY,  
Engineer-in-Chief,

Marconi's Wireless Telegraph Co. Ltd.

## The Darlington Connection

MR. O. Greiter's article (August issue, p. 397) is a welcome addition to the rather sparse literature on the basic theory of transistor stages having really high input impedance. The American system of patent numbering does not necessarily include the application date and there is little reference to Darlington's original work. This is to be found in American Patent 2,663,806 entitled "Semiconductor Signal Translating Device" by S. Darlington and assigned to Bell Telephone Laboratories Inc. Application; 9th May, 1952 and abstracted in the Official Gazette of 22nd December, 1953 p. 1108.

The original idea involved a U-shaped semi-conductor wafer of n-p-n-p-n construction with inter-connections to give the form of circuit shown in Fig. 1 of the article.

Derby

T. J. WYNN

Electrical Engineering Dept., Derby and District College of Technology.

## E.M.F.

REFERRING to the remarks of "Free Grid" in the October issue concerning "e.m.f.", it should be pointed out that naturally it is a force which sets electrons in motion, so the term "electro-motive force" seems to describe our ideas of both the action and its cause. However, this being a force, we ought to measure it by newtons, dynes, ponds, etc., instead of volts.

If, therefore, we prefer to regard a potential difference

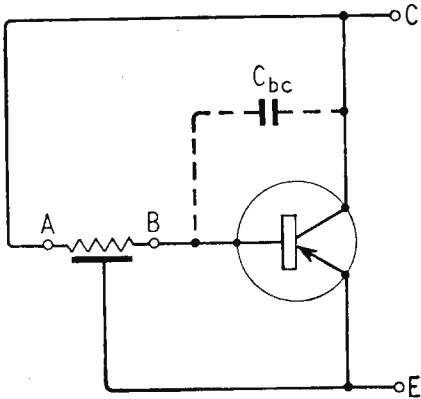
as the macroscopically "evident" cause for an electric current, it would appear expedient to employ a different word such as one of those suggested by "Free Grid." Incidentally, why not "tension"? This word, of course, is ambiguous in that it designates either an electric potential difference or a mechanical (or, for that matter, psychical) stress. But since "voltage" has come to be rather commonly used for any potential difference, we might as well reserve "tension" for a specific potential difference, viz. the one inside a power source (which latter, by the way, had better be called current source).

As to terminological consistency, it may be doubtful whether a form like "tendance" would ever become popular, what with the "t" in front of the suffix missing. Still, one might remember such a lucky exception to the rule as "impedance" and scoff at anyone to whom the meaning of "tendance" is not instantly and unequivocally clear. Or would you?

Selb, KARL H. OLBRIGHT  
W. Germany.

### The Indusistor

IN his letter in the June 1962 issue, Mr. Draganescu has expressed the opinion that it is possible to compensate the transistor base to collector capacitance  $C_{bc}$  by a distributed RC network inserted between the collector,



base and emitter leads, as shown in the accompanying diagram. My calculations, however, lead to the directly opposite conclusion, viz., that the above arrangement, instead of compensating  $C_{bc}$ , will add a capacitance to  $C_{bc}$  at all frequencies. The analysis is presented below in brief.

For a uniform RC line, the line voltage and current at any point at a distance  $x$  from the load end are given\* by

$$E = E_r \cosh(\sqrt{RY}x) + I_r \sqrt{R/Y} \sinh(\sqrt{RY}x) \quad \dots (1)$$

$$I = E_r \sqrt{YR} \sinh(\sqrt{RY}x) + I_r \cosh(\sqrt{RY}x) \quad \dots (2)$$

where  $E_r$  and  $I_r$  are respectively the values of  $E$  and  $I$  at the load end,  $R$  = line resistance per unit length,  $Y = j\omega C$ ,  $\omega = 2\pi \times$  frequency and  $C$  = line capacitance per unit length. The Z-matrix elements of the equivalent four-terminal network of a length  $L$  of the line can be obtained from (1) and (2) as:

$$Z_{11} = \left( \frac{E}{I} \right)_{x=L, I_r=0} = \frac{R}{\sqrt{ju}} \coth(\sqrt{ju}L) = Z_{22} \quad \dots (3)$$

$$Z_{12} = \left[ \frac{(E)_{x=0}}{(I)_{x=L}} \right]_{I_r=0} = \frac{R}{\sqrt{ju} \sinh(\sqrt{ju}L)} = Z_{21} \quad \dots (4)$$

where  $u = \omega CR$  and  $Z_{11} = Z_{22}$  and  $Z_{12} = Z_{21}$  follow from considerations of symmetry and passivity respectively.

In the circuit above, the A and B ends of the line can be considered as approximately open and short circuited so that the impedance presented between A and B will be given by

$$Z = Z_{11} - Z_{12}^2/Z_{11} \quad \dots (5)$$

Combining (3) to (5) and simplifying gives

$$Z = (R/\sqrt{ju}) \tanh(\sqrt{ju}L) \quad \dots (6)$$

Since  $\sqrt{2j} = 1 + j$ , the admittance  $Y = 1/Z$  can be written as

$$Y = (1/R_1) u_1 (1 + j) \coth\{u_1(1 + j)\} \quad \dots (7)$$

where  $u_1 = L\sqrt{u/2}$  and  $R_1 = RL$ . Separating  $Y$  into real and imaginary parts, we get

$$Y = \frac{u_1 [(\sinh 2u_1 + \sin 2u_1) + j(\sinh 2u_1 - \sin 2u_1)]}{2R_1(\sinh^2 u_1 + \sin^2 u_1)} \quad (8)$$

$Y$  can be seen to be the parallel combination of a conductance  $g$  and a susceptance  $b$ . The latter is given by

$$b = \frac{u_1(\sinh 2u_1 - \sin 2u_1)}{2R_1(\sinh^2 u_1 + \sin^2 u_1)} \quad \dots (9)$$

Since  $\sinh 2u_1$  is always greater than  $\sin 2u_1$ , we note from (9) that  $b$  cannot be negative at any frequency i.e.  $Y$  cannot be inductive. Thus in the arrangement of Fig. 1, the distributed RC network will always add a capacitance to  $C_{bc}$ .

The defect in Mr. Draganescu's argument is that he does not consider the effect of the shunt arms in the equivalent  $\pi$ -circuit of the distributed RC network.

Kalyani, Nadia, S. C. DUTTA ROY,  
W. Bengal, India. Dept. of Physics,  
University of Kalyani.

\*R. W. Johnson, "Extending the frequency range of the phase shift oscillator," *Proc. I.R.E.*, Vol. 33, pp. 597-602, September, 1945.

### Resonance

AS a novice, I must protest. Mr. Farquhar's Australian letter aids the conception of another bastard.

Anti-resonance is tidy and meaningful, he says, and "pro-resonance" is its complement. They are certainly full of the wrong meaning (how can resonance be against itself?), and they are as tidy, and as informative as a closed telescope.

Such terms, which conceal meaning from all except initiates who know the code by heart, are far from common already; and very obstructive and misleading they can be to the newcomer.

Certainly, it is a good idea to match the effects themselves rather than pick up epithets from the circuits.

What about "impedant" and "conductive" resonance? Is there any technical objection to them? They do convey a glimmer of their true natures on first acquaintance. And we do know their families.

Morecambe, Lancs. N. F. HALL

### CLUB NEWS

**Derby.**—Meetings of the Derby and District Amateur Radio Society are held each Wednesday at 7.30 at 119 Green Lane. At the January 9th meeting the subject to be considered will be the alignment of communications receivers. On January 23rd there will be an exhibition of members' equipment.

**Edinburgh.**—"Machine Tool Control" is the title of the talk to be given by J. S. Sibbald, of Ferranti, at the January 10th meeting of the Lothians Radio Society which meets on the 2nd and 4th Thursdays of each month at 7.30 at the Y.M.C.A., 14 South Saint Andrew Street, Edinburgh 2.

**Halifax.**—A talk on "Radio on Stamps" will be given by Mrs. M. I. Shaw (G3OMM) at the January 30th meeting of the Northern Heights Amateur Radio Society. The club meets at 7.30 at the Sportsman Inn, Ogden.

**Spenn Valley** Amateur Radio Society meeting on January 24th will be addressed by S. D. Jones who will talk on communication systems of British Railways. The club meets on alternate Thursdays at 7.15 at the Grammar School, Heckmondwike.

**Sheffield** Amateur Radio Club now has its own club room at 8 Sandbeck Place, Sheffield 11, where meetings are held at 8.0 on the second and fourth Fridays in each month.

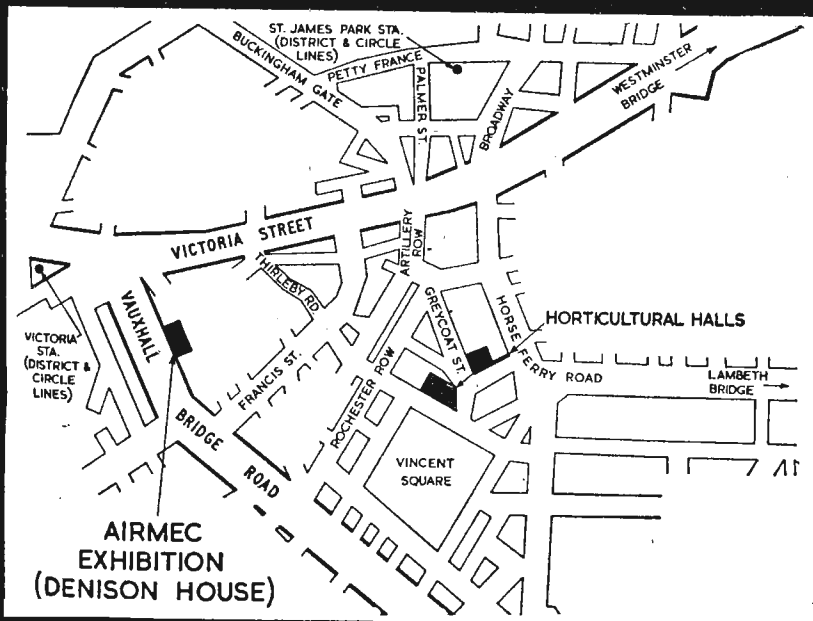
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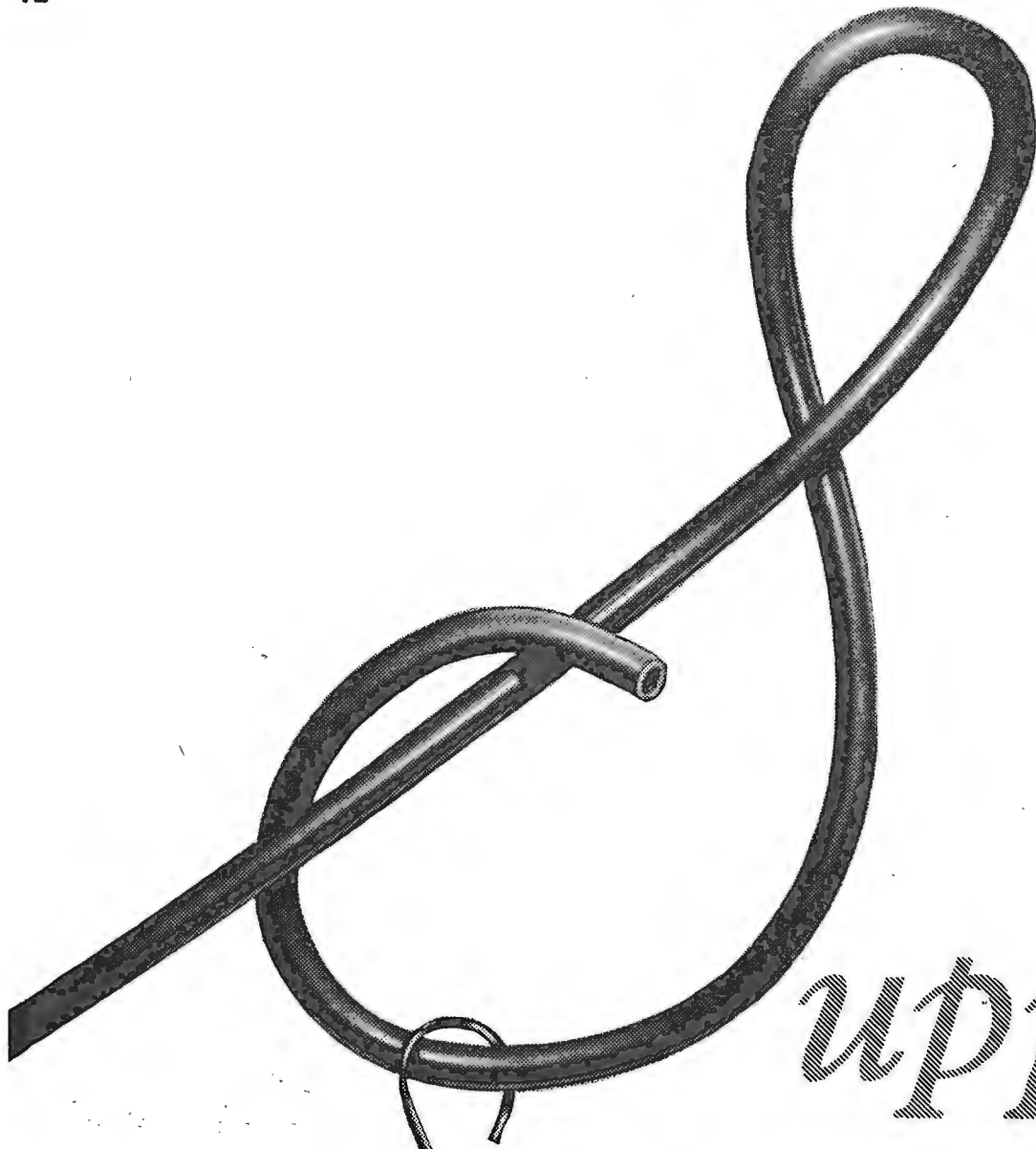
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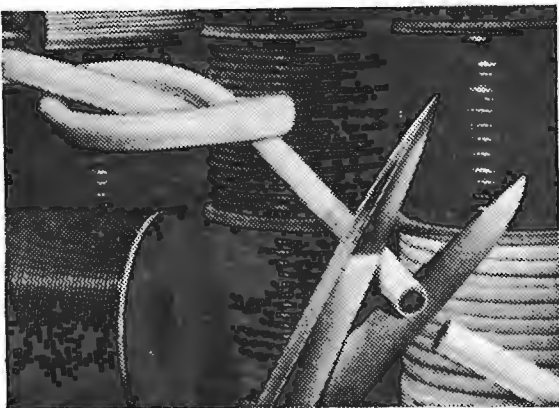
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# OSCILLATORS: a Monistic Approach

## 1. — ACTIVE CIRCUITS IN TANDEM WITH PASSIVE FOUR-TERMINAL NETWORKS

By THOMAS RODDAM

ONE of the curious things about random events is that they produce a subjective effect of being bunched. This should not be confused with the results of long psychological studies which show that bus drivers feel less lonely if they can converse at every stop with conductors of buses of the same number, while statements of average route density will bemuse the passenger, so that good working conditions, that is five buses to a convoy, can be combined with a six-minute average interval, that is one convoy every half-hour.

I am not sure that I do not regret this opening paragraph, because I find that I am suggesting that editors select the contents of the technical journals entirely at random and I should hate to be told that the Editor of this journal had got a new pin. Leaving this question rather sharply, I would suggest that we do find that some aspects of the art are "in" and

*trische Nachrichten-Technik*, p.93, 1929). Since a complete analysis of one of the named oscillators, Hartley, Colpitts, or whatever, takes up only one side of a sheet of octavo paper, it did not occur to me to publish what seemed to be self-evident.

This classification by Cote is a classification of linear oscillators and it seemed to me that an alternative classification into linear and non-linear could be equally valid. Is there any real point, however, in trying to fit a whole collection of different circuits into a small number of straitjackets? This is what they do in the grammar books and you know only too well that the everyday verbs are the irregular verbs, that the grammarian can never get from his system the difference in meaning between the forms "to be sent", "to be sent up" and "to be sent down".

There are benefits to be obtained by lumping circuits into classes and it appears to me that they are substantial benefits. We are forced to separate out the essential features of the circuit from the trivial: we can devote more energy to the study of the essential features because we are not distracted by the trivial: we can easily see the missing combinations which can provide us with new variants, and we can confirm that these variants are probably of little value without waiting for them to be invented as new circuits.

Any system of classification is subject to criticism on two counts. The actual class types themselves are rarely easy to define and when they are defined the objects to be classified never seem to fit properly into the classes. You will find that your local public library, the very heart of the class system, will decide that two copies of the same book, bought at different times, should be shelved quite far apart. I do not claim any finality for the results of this article because I regard it as an enquiry into ways of classifying oscillators, an attempt to clarify a muddy pond by stirring it up.

We can begin with the division of oscillators into two broad classes, those with four-terminal passive networks and those with two-terminal passive networks. The first class represents what we call the feedback oscillators while the second class is the

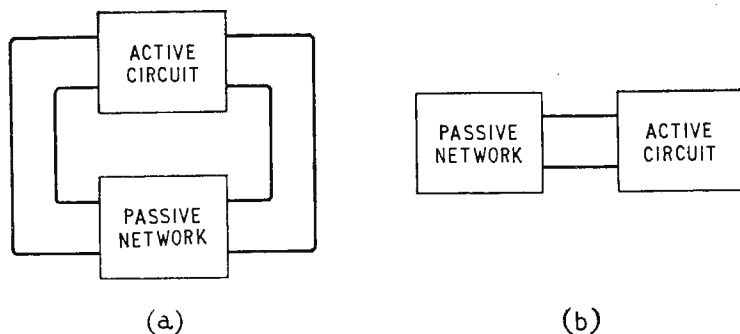


Fig. 1. Two main classes of oscillator: (a) with four-terminal passive networks (feedback oscillators) and (b) with two-terminal passive networks (negative-resistance oscillators).

some "out" during any particular season. When a topic is "in" we find it ground to small pieces before our very eyes and then, suddenly, all is forgotten.

We do not seem to hear much about oscillators at the moment. Some of us are interested in inverters but the ordinary general-purpose oscillator seems to be accepted as just part of the background. It has always seemed to me that there was still too much of the old ham about the oscillator field, too many named circuits which hide the essential simplicity of the whole subject. My mind was stimulated by noticing, when I was checking another reference, some correspondence about the matrix analysis of oscillator circuits. The affair started with a classification of oscillators by Cote (*I.R.E. Trans. Circuit Theory*, p.181, Sept. 1958) and was followed by a letter by Brodie in which the oscillator was treated as an active element in tandem with a passive network (*ibid*, p.69, March 1960). I found this approach sympathetic, for I had used it myself in 1936 when I first encountered the classic Strecker and Feldkeller paper on the use of matrices (*Elek-*

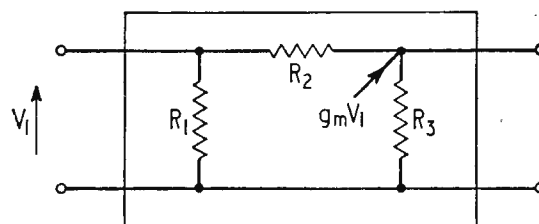


Fig. 2. Equivalent circuit of active network of feedback oscillator of Fig. 1(a) in case where network is linear.

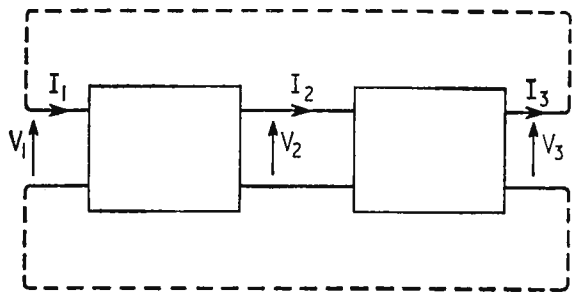


Fig. 3. Version of feedback oscillator of Fig. 1(a) obtained by cutting feedback loop and "unrolling".

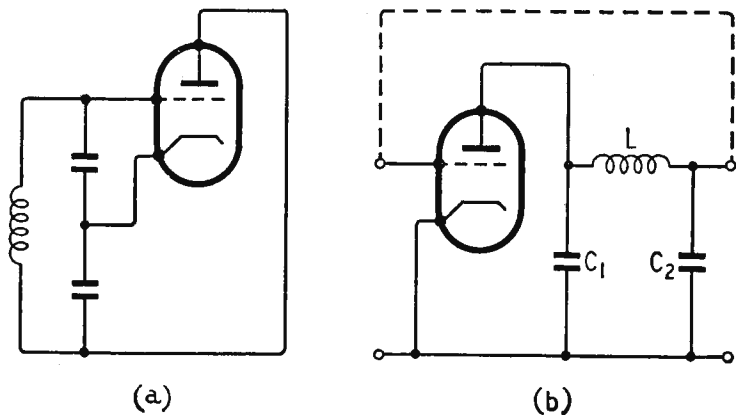


Fig. 4. Colpitts oscillator in rudimentary textbook form (a) and rearranged (b).

class of negative-resistance oscillators. These are illustrated in Fig. 1. The feedback oscillators are the most commonly used circuits and they lend themselves to elegant methods of analysis. We know that the active circuit, the valve or transistor, must have some input impedance and that the output terminals can be considered to present some other impedance in shunt with a current generator. All in all, the active network may have an equivalent circuit of the form shown in Fig. 2, at least so long as we consider it to be a linear network. The resistance elements may well have reactive terms associated with them but it is easier just to keep those in our minds for the moment.

In analysing the circuit of the feedback oscillator the simplest approach is to make a cut in the loop and unroll it to the form shown in Fig. 3. We can then treat the active network and passive network in tandem as a simple amplifier system and finish up with expressions connecting  $V_1, I_1, V_3, I_3$ . For steady oscillations to be maintained we must set the two conditions  $V_1 = V_3$  and  $I_1 = I_3$ . The resulting equations will give us the complex characteristic frequencies of the whole system and in normal circuits this means the frequency of oscillation and the damping, which must be zero if the gain of the active network is correctly chosen to give sustained oscillations.

The simplest illustration of this can be seen in the Colpitts circuit of Fig. 4a. The rudimentary textbook form is easily rearranged to the structure of Fig. 4b. It is not certain whether the procedure which follows is always desirable and indeed it can introduce a certain amount of extra work. We compare the terminals of the network in Fig. 2 with the structure of Fig. 3 and transfer the passive elements in the active circuit box to the passive circuit box. For the Colpitts oscillator this results in the structure of Fig. 5. In practice, of course, the

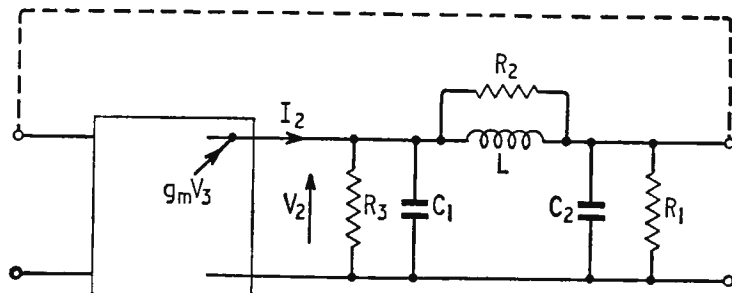


Fig. 5. Transformation of Colpitts oscillator circuit of Fig. 4(b) by general procedure of comparing terminals of network in Fig. 2 with structure of Fig. 3 and transferring the passive elements in the active circuit box to the passive circuit box.

element  $R_2$  will be the grid-anode capacitance if we are using a valve circuit but will be resistive if we are using a transistor.

Let us ignore  $R_2, R_1$  and  $I_3$ , and write  $G_3 = 1/R_3$ . It is a matter of a few lines to arrive at the equations

$$V_2 = (1 - \omega^2 LC_2) V_3$$

$$I_2 = [(G_3 + j\omega C_1)(1 - \omega^2 LC_2) + j\omega C_2] V_3$$

Now of course  $I_2 = g_m V_3$ , so that

$$g_m = G_3(1 - \omega^2 LC_2) + j\omega [C_1(1 - \omega^2 LC_2) + C_2]$$

The term which gives the frequency is the imaginary term, which gives us

$$C_1 + C_2 - \omega^2 LC_1 C_2 = 0$$

$$\text{or } \omega^2 L [C_1 C_2 / (C_1 + C_2)] = 1$$

We can substitute in this to find the necessary value of  $g_m$ .

In this particular example we see that if there is only one resistance in the system, or perhaps we should count  $1/g_m$  and say two, the frequency is independent of the resistance. If we made  $G_3 \rightarrow 0$  we should get also  $g_m \rightarrow 0$ , a solution which leaves us with just a tuned circuit of infinite Q oscillating away to itself. When we add a second resistance,

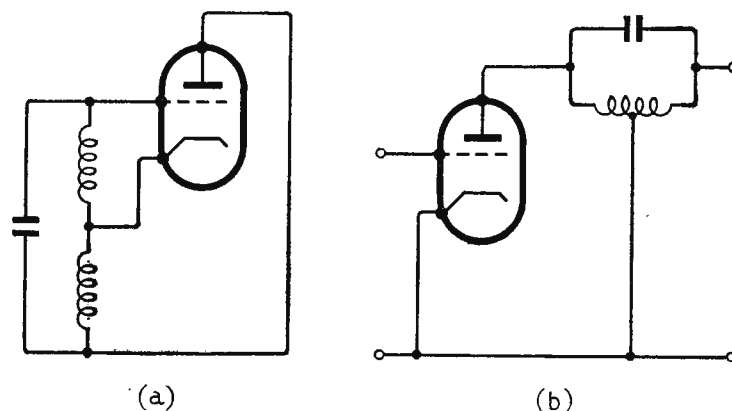


Fig. 6. Hartley oscillator in standard (a) and rearranged forms (b).

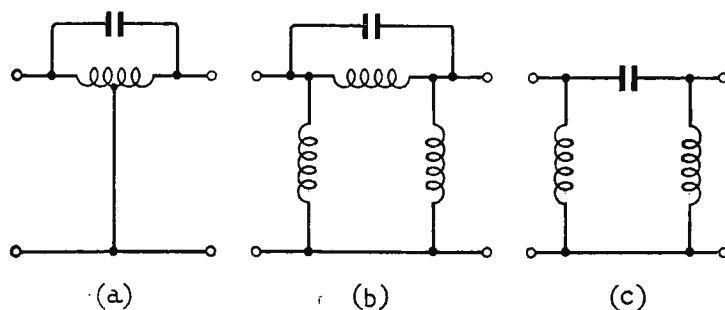
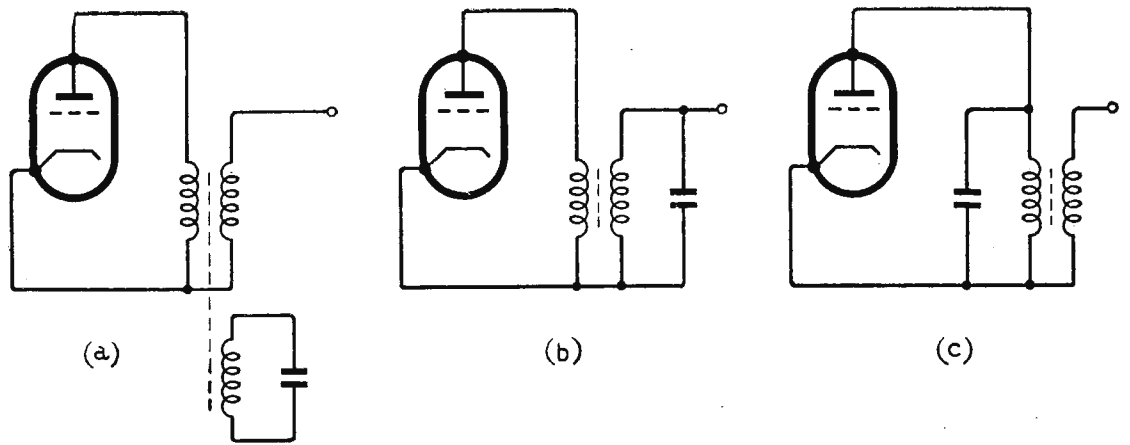


Fig. 7. Inductance system of Hartley oscillator (a) and respectively, equivalent circuits with (b) and without (c) coupling between the coils. (c) is more accurately described as a dual of the Colpitts circuit.

Fig. 8. Meissner, tickler feedback and reversed tickler feedback oscillators respectively.



by accepting a finite value for either  $R_1$  or  $R_2$ , we find that the frequency is displaced from the value given above by the presence of the resistance.

At this stage we may construct a table showing the conventional amplifier circuits and the way in which they fall into this class. There are some interesting obscurities which are illuminated and we meet the first problem with the Hartley oscillator of Fig. 6a. We can rearrange this into the form of Fig. 6b and accept this as our form for analysis, or we can use an equivalent circuit for the inductance system if we assume that the two coils are coupled. The form shown in Fig. 7b looks a little off the track, but the form shown in Fig. 7c, which we shall obtain with no coupling, is obviously a dual of the Colpitts circuit. I have always assumed, I now find in error, that the circuit of Fig. 7c was the Hartley circuit, but looking in Terman (*Radio Engineers' Handbook*, p. 480, McGraw-Hill) I find that he talks of "opposite ends of the tank circuit", which implies moderately good coupling between the two inductors. The dual of the Colpitts circuit is anonymous and ignored.

The curious thing is that in Fig. 8a, b and c—the Meissner, tickler feedback and reversed feedback circuits (the names come from Terman)—we see circuits which it is hard to justify separating from each other or from the Hartley circuit proper. What is more, all these circuits, in their ideal form, are not necessarily treated as four-terminal oscillators at all. They are probably most easily considered to be two-terminal negative-resistance circuits.

The last of Terman's set of common types of oscillator is the tuned-anode, tuned-grid oscillator, which relies on the capacitance between anode and grid to make it operate. The circuit and its rearranged form are given as Fig. 9a and b. Terman's book is so valuable that his few lapses are of special interest and here we find one of them. He accepts the fact that both of the anti-resonant circuits will be inductive at the frequency of oscillation and then states that the circuit reduces to the Hartley circuit, whereas it actually reduces to the circuit shown in Fig. 7c, the dual of the Colpitts circuit.

Consideration of Fig. 9b must put into our minds the corresponding Colpitts variant of Fig. 10a, which we can draw in conventional form as Fig. 10b. This we can recognize as the circuit usually called the Clapp circuit. At this point it is worth comparing Figs. 4b, 7c, 9b and 10a. The structures of the passive networks are all structures which we find in tables of simple filter networks and are full sections of, in order, the constant- $k$  low-pass filter, the constant- $k$  high-pass filter and two forms of three-element band-pass filter. It is rather interesting

to notice that the common feature of these circuits is that the phase shift in the ordinary Zobel analysis ranges from zero to  $\pm 180^\circ$  through the pass-band and that the frequency of oscillation is at one edge of the band. We can immediately predict that there should be two more oscillator structures of this kind, those indicated by Fig. 11a and b.

We can see something else which requires detailed study. The feedback of harmonics through the network may be attenuated, as it is in the Colpitts circuit, or it may have a substantial phase-shift, as it has in the circuit of Fig. 7c. In the Clapp circuit of Fig. 10b we have the attenuation condition, for we operate at the upper end of the pass-band; while in the circuit of Fig. 9b we operate at the lower edge of the pass-band and the high-side cut-

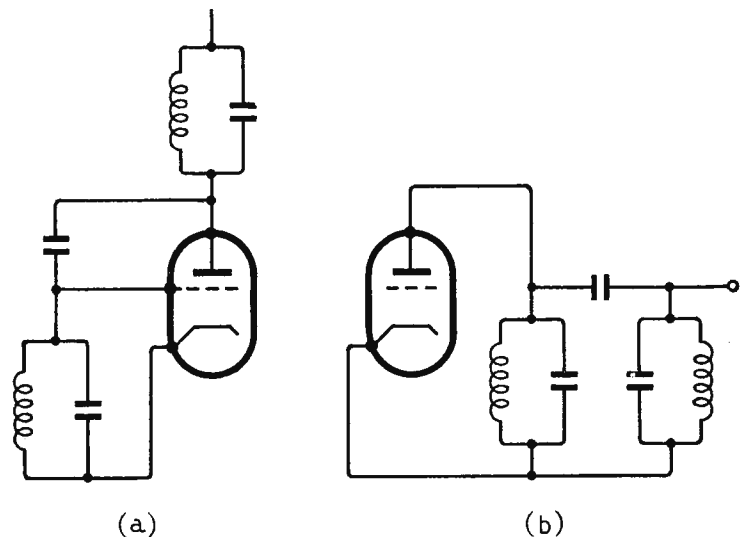


Fig. 9. Tuned-anode tuned-grid oscillator in its standard (a) and rearranged forms (b).

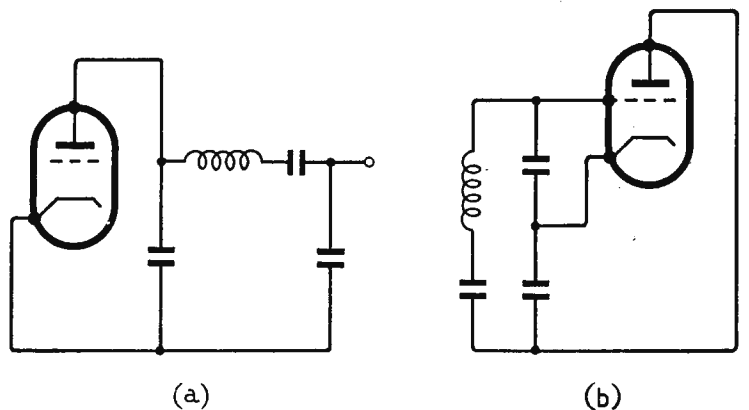


Fig. 10(a). Colpitts oscillator variant corresponding to rearranged form of tuned-anode tuned-grid oscillator of Fig. 9(b). (b). Conventional form of (a), usually called the Clapp circuit.

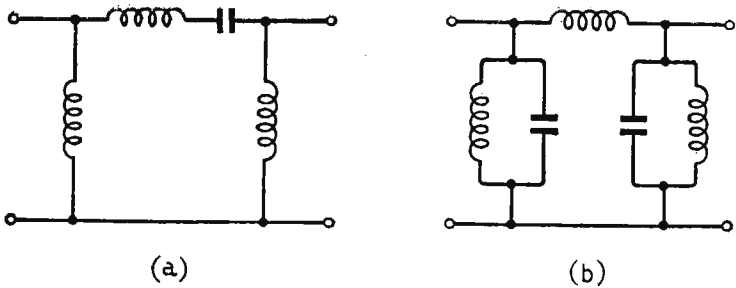


Fig. 11. Two other possible three-element filter oscillator structures.

off is very gentle. We must not attach too much importance to the  $\cos$  and  $\cosh$  expressions we find in the filter tables, for the terminations we use are certainly not the filter image impedances, but we can accept the attenuation and phase characteristics as hints on how the circuits may behave. You will remember, of course, that intermodulation of harmonics is one of the factors which affects the way in which the valve or transistor parameters influence the frequency of oscillation.

Obviously we can go on to construct oscillators based on the whole family of filter structures. There are two points of interest which must be noted. The first is that we should expect that the  $180^\circ$  phase-shift of a single section would be an asymptotic value, so that we should never really get the full  $180^\circ$  we need for instability. The filter must be working in a mismatched state so that we can get a small excess phase-shift to overcome the dissipation rounding of the phase characteristic. This indicates that the terminations, which are associated with the resistances of the active device, play more part in determining the frequency than we should predict from our simple theory. From this we go on to note that the effective dissipation in a band-pass circuit is inversely proportional to the fractional band-width. This is of very great importance because it is a factor which acts in the opposite sense to the elementary band-pass behaviour: we get our  $180^\circ$  phase-shift across the pass-band, and thus more degrees per cycle (American) and we expect the band-pass circuit to be more stable. It ain't necessarily so. The second point is that although the constant- $k$  band-pass filter is a structure which may tempt us, it will have two possible frequencies of oscillation, one at each band edge.

One particular situation in which we use a more complex band-pass structure is in the two elementary crystal oscillator circuits. These seem to be degenerate cases of five-element systems and although I have no intention of confirming this I suspect that the degeneracy is responsible for eliminating the second  $\pm 180^\circ$  frequency from the circuit. The circuits and their networks are shown in Fig. 12 but without a more thorough examination I would hesitate to guarantee that the grid-cathode capacitance of Fig. 12c and d is essential. A grid-cathode admittance of some kind there must be, since otherwise there will be no current through the crystal, and certainly the capacitance will exist so that we should include it in any calculations. It plays an important part in fixing the frequency of oscillation.

The pursuit of other single-section networks is an exercise for anyone who wishes to produce a catalogue of oscillators. This will be a tedious occupation and will involve a search through the literature in order to identify the variants already described: they will all be variants of the single basic type.

Since the image phase-shift of the network only approaches  $180^\circ$  asymptotically the oscillation, as we have already said, must depend on mismatch effects. The performance of this class of oscillator can be considerably improved by designing it to give a total phase-shift of  $270^\circ$  and allowing some of the mismatch effects to cancel out at the frequency which gives the  $180^\circ$  phase-shift needed for oscillation. This leads us to the family of stabilized oscillators. Typical of the network used is that shown in Fig. 13. Terman gives (*ibid*, p. 487) a collection of sixteen circuits of this kind. If we take the form shown in Fig. 14 we can write down after a few lines of simple analysis

$$\begin{aligned} V_1/V_2 &= [1 + Y_2(R_1 + Z_1)] [1 + Z_3(Y_4 + G_2)] + \\ &\quad (R_1 + Z_1) (Y_4 + G_2) \\ &= [1 + Y_2Z_1 + Y_2R_1] [1 + Y_4Z_3 + G_2Z_3] + \\ &\quad R_1G_2 + Z_1Y_4 + R_1Y_4 + Z_1G_2 \end{aligned}$$

We only need the frequency equations and if the  $Z$ 's and  $Y$ 's are pure imaginaries we have the equation (for  $V_1/V_2$  is real):

$$0 = (1 + Y_2Z_1) G_2Z_3 + Y_2R_1 (1 + Y_4Z_3) + R_1Y_4 + Z_1G_2$$

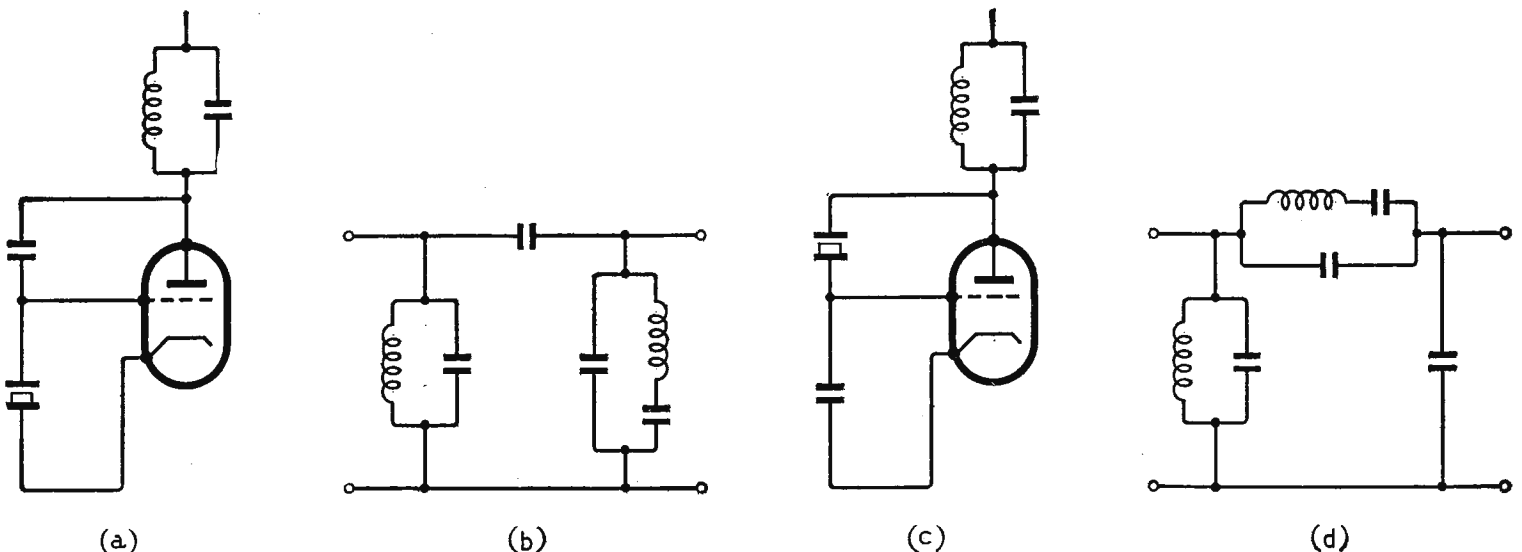


Fig. 12. Two elementary crystal oscillator circuits (a) and (c) and their corresponding networks (b) and (d).

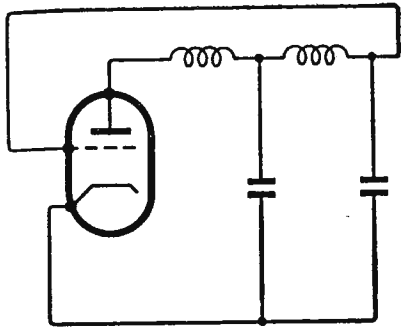


Fig. 13. Typical stabilized oscillator network.

For the specific network of Fig. 13 we have

$$0 = (1 - \omega^2 L_1 C_2) j\omega L_3 G_2 + j\omega C_2 R_1 (1 - \omega^2 L_3 C_4) + j\omega C_4 R_1 + j\omega L_1 G_2$$

$$= (1 - \omega^2 L_1 C_2) L_3 G_2 + (1 - \omega^2 L_3 C_4) C_2 R_1 + C_4 R_1 + L_1 G_2$$

$$\therefore L_3 G_2 + C_2 R_1 + C_4 R_1 + L_1 G_2 = \omega^2 (L_1 L_3 C_2 G_2 + L_3 C_2 C_4 R_1)$$

and  $\omega^2 = \frac{(L_1 + L_3) G_2 + (C_2 + C_4) R_1}{L_1 G_2 + C_4 R_1} \times \frac{1}{C_2 L_3}$

In order to get stabilization against small changes in  $G_2$  we want to have  $d\omega^2/dG_2 = 0$ , so that  $(L_1 G_2 + C_4 R_1) (L_1 + L_3) = [(L_1 + L_3) G_2 + (C_2 + C_4) R_1] L_1$

Suppose that we make  $G_2 \rightarrow 0$ . Then we have  $C_4 (L_1 + L_3) = L_1 (C_2 + C_4)$  or  $L_3/L_1 = C_2/C_4$

This, which is independent of  $R_1$ , is one of the expressions given by Terman. You observe that the frequency of oscillation is given by  $\omega^2 = (C_2 + C_4) / L_3 C_2 C_4$  and will have this value for small values of  $G_2$ . There is a good deal more algebra involved in exploring these circuits to the full. We have ignored the question of the gain needed to enable the system to oscillate, for example, for this is given by the real part of the  $V_1/V_2$  equation above. The point is that by this fairly simple procedure we can treat any oscillator circuit of this broad general kind.

Need the network be a ladder network of reactances? The answer is that it is simply a four-terminal network of whatever kind we choose. We can take, for example, the well-known form shown in Fig. 15, a form which can be modified to the alternative RC low-pass structure, to a pair of RL structures, or can be extended, first to a system with four or more RX units and then to the even more satisfactory form of the distributed RC network. In all these we have the simple  $180^\circ$  phase-shift condition, but with

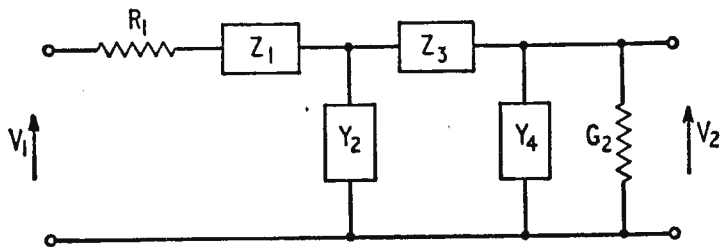


Fig. 14. General form of stabilized oscillator network.

the RC and RL networks we no longer have the idea of image parameters to blind us and we see that we must use networks which will pass through  $180^\circ$  and which will be asymptotic to at least  $270^\circ$  phase-shift.

It is typical of the fragmentary way in which the oscillator circuit field has been extended that it is at this point that we look back to Fig. 1a and note that the active circuit need not have a phase-shift of  $180^\circ$ . There is no reason why we should not use

two stages of amplification to give us a zero (or  $360^\circ$ ) phase-shift. We can also use a transformer to give us a phase-shift of  $180^\circ$  and retain the single-stage operation.

The oscillator circuits which follow from this approach are of two kinds, the crystal oscillator circuits and some RC oscillators. It may be noted that the RC configurations all have corresponding RL combinations but that these are rarely if ever used for purely practical reasons: a good capacitor is very much cheaper than an inductor of lower quality. The crystal oscillator circuits have corresponding LC circuits which are sometimes used.

Typical of the crystal oscillator circuits using a transformer is the bridge network known as the

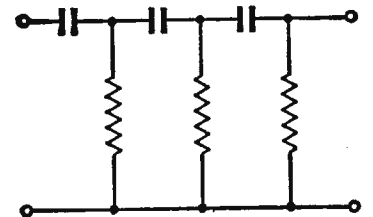


Fig. 15. Another possible oscillator four-terminal network.

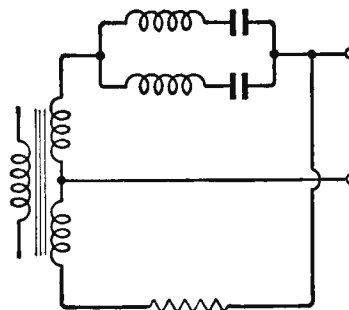


Fig. 16. Network for two-frequency LC form of Meacham crystal oscillator circuit.

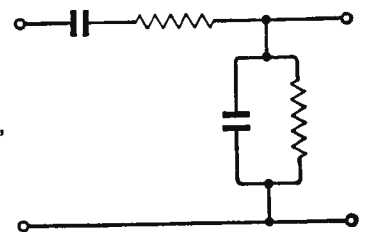


Fig. 17. Wien bridge network.

Meacham circuit, which is also used to provide a highly stable LC oscillator. In its LC form it is of special interest, because it can be used to provide a number of separate frequencies from a common amplifier. The network for a two-frequency oscillator is shown in Fig. 16 and the two frequencies of oscillation of this arrangement are the resonant frequencies of the two LC branches. I do not wish to discuss the limitations of this arrangement at the moment, for they are associated with the way in which the oscillation amplitude is controlled, a matter of very great importance and a key feature of the Meacham bridge.

The RC circuits are of two kinds, those which give a voltage loss and those which provide a voltage step-up. The Wien bridge network, although it is not used for this purpose in a bridge circuit, is shown in Fig. 17 and requires that there should be some gain between input and output. The circuit is often used in a form which can in fact be described as a complete bridge, but this involves the amplitude-control system. It will be seen that the impedances of the active part of the circuit will have a very important part in determining the frequency of

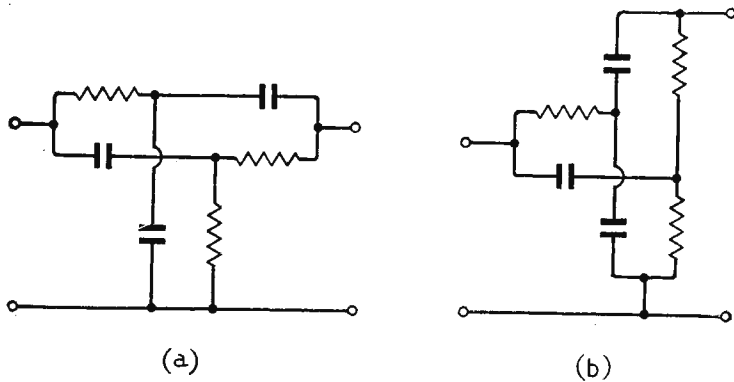


Fig. 18. Two voltage-gain RC circuits. The unsymmetrical parallel-T network shown in (a) can be treated as a different connection of the "over-balanced" symmetrical parallel-T network shown in (b).

operation, and the use of negative feedback and of pentode valves to provide controlled and extreme values of impedance is common practice. This particular circuit is, of course, very well known and the requirements for good stability have been studied very fully, especially in connection with variable-frequency oscillators.

The voltage-gain RC circuits are less well known but a number of them have been described by the author in *Wireless World* (March 1954, p.106). The unsymmetrical parallel-T network shown in Fig. 18a is one of the circuits which can be used and in a simple analysis it can be treated as a different connection of the "over-balanced" symmetrical parallel-T network shown in Fig. 18b. This type of circuit can be made to give a voltage gain of more than the  $(\mu+1)/\mu$  which is needed to feed back from cathode to grid in a cathode follower stage, and will thus give a zero phase-shift oscillation condition.

We can go on producing more feedback networks until the cows come home. One rather interesting one is obtained by doing a transformation on Fig. 18 to get Fig. 19a, which is very much like a stabilized

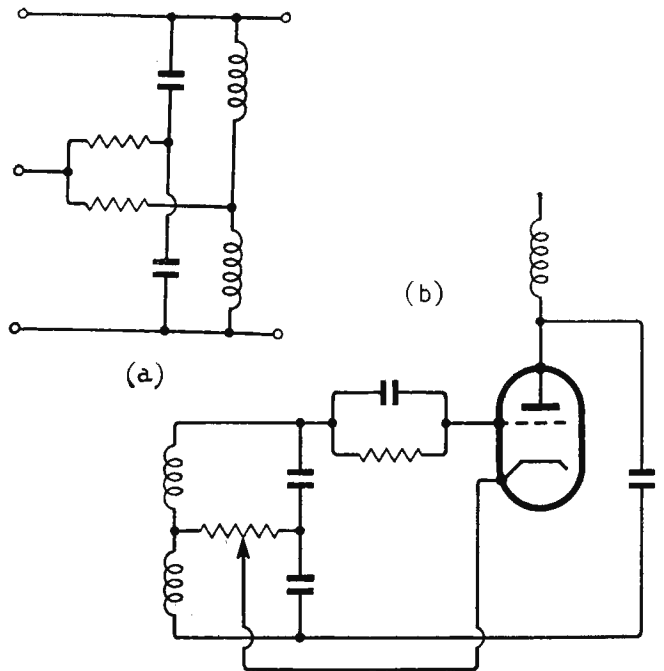
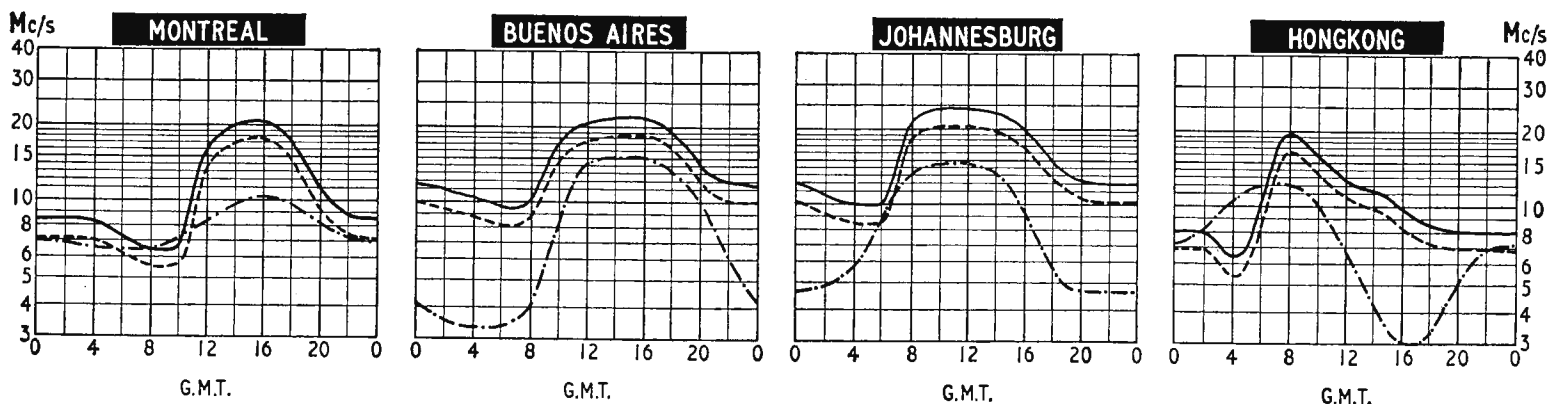


Fig. 19. Transformation of Wien bridge network (a) also shown redrawn in complete circuit (b).

circuit due to Kusonose and Ishikawa (*Proc. I.R.E.* p.310, Feb. 1932), although by drawing the circuit in the form of Fig. 19b they give quite a different interpretation of it and therefore make the tapping point on their resistance variable so that the most stable position can be found experimentally.

It is clear that we must defer the question of how we are to maintain the essential condition of the standardized gain of the active circuit to a later article, in which we may find that we must break up this main four-terminal class into a new set of subclasses. We may also find it necessary to introduce that bug-bear of the classifier, the class of the unclassifiable.

## H. F. PREDICTIONS — JANUARY



The prediction curves now show the median standard MUF, optimum traffic frequency and the lowest usable high frequency (LUF) for reception in this country. Unlike the MUF, the LUF is closely dependent upon such factors as transmitter power, aeriels, local noise level and the type of modulation: it should generally be regarded with more diffidence than the MUF. The LUF curves shown are those drawn by Cable and Wireless,

Ltd., for commercial telegraphy and they serve to give some idea of the period of the day for which communication can be expected. The LUF curve for Montreal takes account of auroral absorption.

# The Zenith-G.E. Stereophonic Broadcasting System

By G. J. PHILLIPS,\* M.A., Ph.D., B.Sc., A.M.I.E.E., and J. G. SPENCER\*

## BACKGROUND OF THE B.B.C. TEST TRANSMISSIONS

**T**HE main factors which are desirable in a system for stereophonic broadcasting can be summarized as follows:—

- (1) It should be capable of transmission on a single radio-frequency channel with no significant increase in bandwidth.
- (2) It should be compatible, that is it should give satisfactory monophonic reception on receivers at present in use by the public.
- (3) It should give stereophonic reproduction in the listener's home which is comparable with that obtainable from good stereophonic disc recordings and furthermore should attain this standard with relatively cheap and simple receiving apparatus.
- (4) It should not reduce the existing service area significantly for monophonic listeners and any reduction for stereophonic listeners should be as small as possible.

Many systems have been proposed over the last few years which meet these requirements to a greater or lesser extent including, in the U.S.A., some for use with a.m. transmitters in the medium-frequency broadcasting band. In Europe, however, interest has been largely confined to those intended for use at v.h.f. In 1960 the B.B.C., in collaboration with several other European broadcasting authorities, took part in a series of laboratory tests to examine the performance of the various systems. A more detailed review of the progress made internationally with special reference to the work co-ordinated by the European Broadcasting Union has been given elsewhere.<sup>1</sup> From the result of this work, the two most promising proposals were selected for further examination.

Before proceeding further it is helpful at this point to consider the general basis upon which the majority of these systems are designed. In order to transmit two separate audio-frequency signals on a single carrier they use the multiplex principle. One of the signals is first used to modulate an ultrasonic subcarrier, the constants of the modulating system being so chosen that the resulting spectrum lies wholly above the audio-frequency range. The modulated signal is then added to the other audio-frequency signal to give the modulating waveform applied to the main transmitter. Normal monophonic receivers tuned to such a transmission will reproduce only the

audio-frequency component of the modulation; stereophonic receivers must be specially designed to carry out the appropriate inverse process to obtain both of the original audio-frequency signals.

The simplest way to broadcast stereophony with such a system is to transmit the left-hand and right-hand signals which comprise the stereophonic programme directly, one as audio-frequency modulation and the other on the subcarrier channel. In this case, however, the monophonic listener would receive one half of a stereophonic signal which would give undue emphasis to sounds originating on one side of the sound stage. This would be most unsatisfactory in balance and would not fulfil the requirement of compatibility. To overcome this difficulty the usual practice is to combine the left- and right-hand stereophonic signals (designated A and B respectively) to form  $A+B$  and  $A-B$ . The  $A+B$  signal, which subjective tests have shown to give satisfactory reproduction as a monophonic version of a stereophonic programme, is transmitted as audio-frequency modulation and the  $A-B$  signal is transmitted on the subcarrier channel. This answers the compatibility requirement for monophonic listeners while stereophonic receivers can easily re-combine the  $A+B$  and  $A-B$  signals to

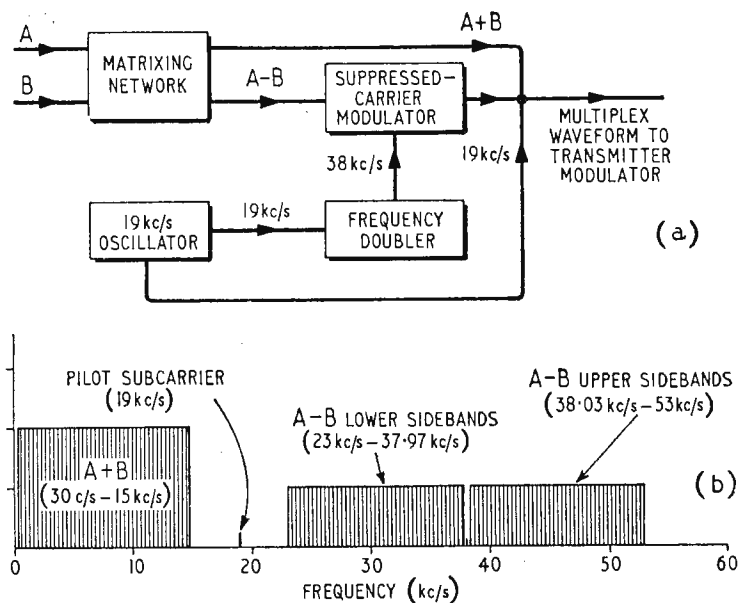


Fig. 1. (a) Block schematic diagram of the stereo multiplex waveform generator in the Zenith-G.E. system. (b) Spectrum of multiplex modulation waveform.

\*B.B.C. Research Department.

reconstitute the original A and B components of the stereophonic programme.

The two systems which emerged from the first series of tests referred to earlier both used the multiplex waveform technique but differed in their methods of subcarrier modulation. The first used a frequency-modulated subcarrier and was similar to that proposed by Crosby in the U.S.A. but with the standards modified to give somewhat better compatible reception. The second was the Zenith-G.E. system adopted in April 1961 by the Federal Communications Commission (F.C.C.) for use in the U.S.A.<sup>2</sup>; this employs amplitude modulation of the subcarrier, but with the subcarrier frequency component suppressed. The main parameters of the two systems are given in Table 1 and the Zenith-G.E. system is discussed in more detail later.

In general terms, the laboratory tests showed that both systems gave satisfactory reception with monophonic receivers with a barely significant reduction in the service range of a transmitter. The service area for stereophonic reception would, however, be materially reduced, again to about the same extent with either system. Bearing in mind the similarity in performance of the two systems, and the desirability of international standardization, the European Broadcasting Union recommended the adoption of the Zenith-G.E. system. The recommendation was, however, conditional on the system performing satisfactorily in field tests of those aspects of performance which could not be fully explored in the laboratory.

Early in 1962 preparations were made by the B.B.C. for the adaptation of one of the Wrotham v.h.f. transmitters, and the first test transmission of stereophony by the Zenith-G.E. system took place in June. It should be emphasized that any transmissions at this stage are intended purely for engineering test purposes; the transmission standards may be altered from time to time and the same programme material may be repeated at each transmission. Moreover, although the remainder of this article is devoted to the Zenith-G.E. system, as specified in the F.C.C. proposals, it must be remembered that it has not yet been decided whether such a system will be used (either in its original or modified form) in the U.K.

**Operation of the Zenith-G.E. System:**—Fig. 1(a) shows in block schematic form how the Zenith-G.E. system multiplex modulating waveform is generated

**Table 1: System Parameters**

	F.M. subcarrier system	Zenith-G.E.* system
Subcarrier frequency	50 kc/s	38 kc/s
Pilot frequency	—	19 kc/s
Peak deviation of main carrier (% of $\pm 75$ kc/s)		
—by A + B signal	80%	90%
—by subcarrier or sidebands	20%	90%
—by pilot signal	—	8 to 10%
Peak deviation of subcarrier	$\pm 20$ kc/s	—

\*The standards given correspond to the F.C.C. recommendation when no S.C.A. ("storecasting") is in operation.

at the transmitter. The left and right audio frequency signals are combined to produce A+B and A-B. The A-B signal is then amplitude modulated on to a 38 kc/s subcarrier, the subcarrier being suppressed to leave the sideband components. In order that the receiver can regenerate the 38 kc/s subcarrier necessary to demodulate the A-B information a pilot subcarrier, at a frequency of 19 kc/s, is transmitted with an amplitude producing a peak deviation of the main carrier of between 8% and 10% of the maximum permitted deviation.

The multiplex modulating waveform applied to the transmitter thus consists of three separate components:—

- (1) The A + B signal, as normal audio-frequency modulation, with a spectrum extending from 30 c/s to 15 kc/s.
- (2) A 19 kc/s pilot subcarrier of constant amplitude.
- (3) The A - B information, in the form of a.m. sidebands of a suppressed 38 kc/s subcarrier, with a spectrum extending from 23 kc/s to 53 kc/s.

A monophonic receiver will reproduce only the A + B signal, the ultrasonic components of the modulation being heavily attenuated by the de-emphasis circuit, so that they are unlikely to produce any undesirable effects in the audio-frequency amplifier.

The quantitative specification of the system, giving the frequency deviation of the main carrier by each of the three components of the multiplex modulating waveform is given in the right-hand column of Table 1.

The phase relationships and sense of modulation for the instantaneous deviation,  $\Delta f$ , of the transmitted carrier as a function of time  $t$ , taking the pilot signal at its mean level, are given by the following expression

$$75 \left[ 0.9 \frac{A+B}{2} + 0.9 \frac{A-B}{2} \sin 2\omega_p t + 0.09 \sin \omega_p t \right] \text{kc/s}$$

where  $\omega_p/2\pi = 19,000$  and the values of the stereophonic signals A and B are restricted within the range  $\pm 1$ .

At this stage one may well ask why the original subcarrier is suppressed and replaced by a pilot signal of small amplitude at half subcarrier frequency. Why not radiate the full original subcarrier, or at least a pilot at the subcarrier frequency? If the full amplitude subcarrier were preserved a considerable proportion of the available deviation of the main transmitted carrier would be occupied by it, even during periods when little or no difference channel information was being conveyed. This would restrict the deviation available for the sum signal and the difference sidebands, and result in a further reduction of the system signal-to-noise ratio. Suppression of the subcarrier is thus a method of improving the signal-to-noise ratio of the system at the expense of some extra complication in the receiver. Sufficient information must be transmitted to enable the receiver to reconstitute the 38 kc/s subcarrier in the correct phase in order to detect the A - B information and this is the purpose of the pilot signal. If the pilot were at the fundamental frequency of 38 kc/s the receiver would be faced with the problem of extracting a steady, unmodulated carrier from a



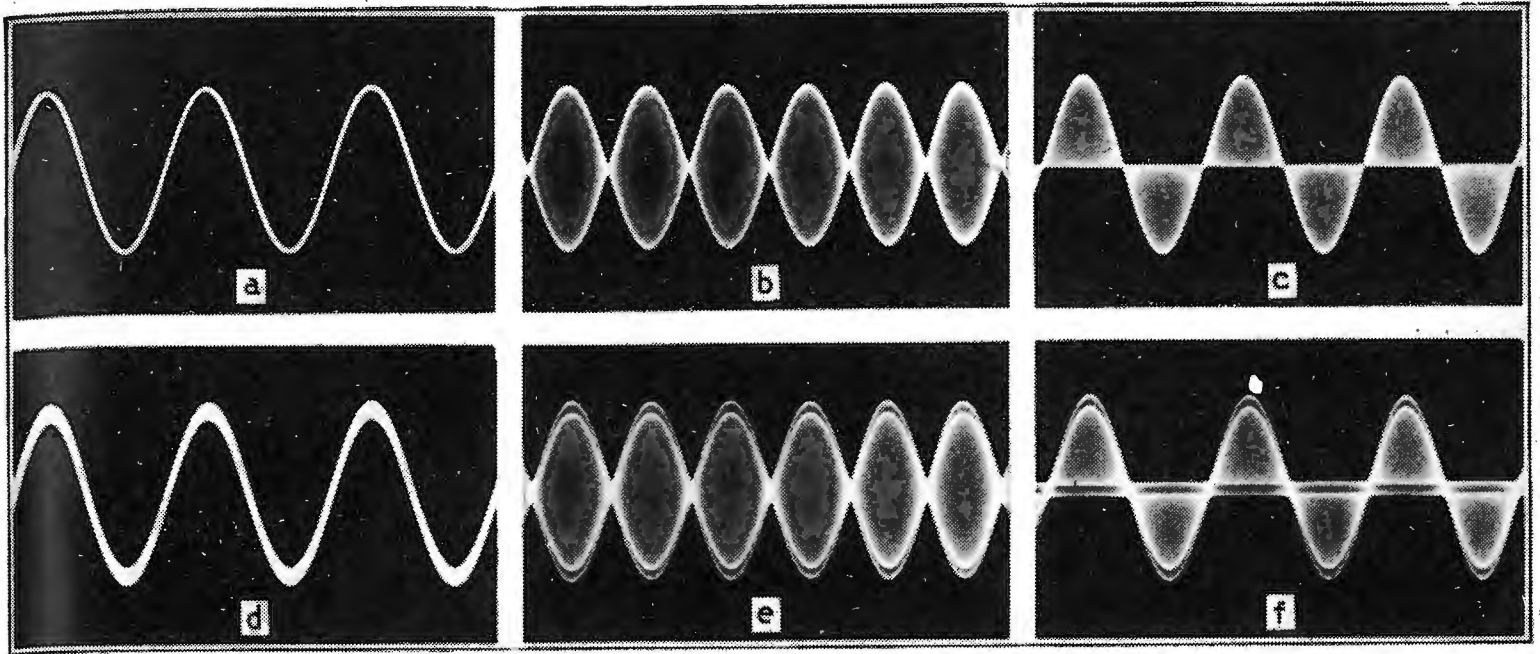


Fig. 2. Multiplex waveforms. (a) Output when 1 kc/s tone is applied in parallel to both channels. (b) Output with same tone fed to both channels but with phase of one input reversed. (c) Input applied to A channel only. (d), (e) and (f). Conditions similar to (a), (b) and (c), but with 19 kc/s pilot subcarrier added at an amplitude 10% of signal modulation.

mass of sideband components which may be considerably greater in amplitude and spaced by as little as 30 c/s in frequency; a formidable problem of filtering. Reference to the spectrum of the multiplex signal given in Fig. 1(b), however, shows that between 15 kc/s and 23 kc/s there exists a spectral "green belt" in which the pilot can enjoy sufficient elbow room to permit simple tuned circuits to provide the necessary filtering.

One minor, but useful, property of the Zenith-G.E. system, to which the use of a half-frequency pilot contributes, is that reversal of the polarity of the multiplex waveform does not interchange the A and B channel outputs as it does for almost any other form of subcarrier system. (Justification of this statement will not be attempted here but if the reader can summon the energy to verify it for himself he will emerge not only with several pages of rough waveform sketches, but also with a profound understanding of multiplex communication systems.) This does confer the advantage that such things as the polarity of discriminator diodes do not have to be specified and eases the position when stereophonic adaptors have to be mated with f.m. tuners for which they were not specifically designed.

It is a feature of the Zenith-G.E. system that if the individual A and B signals are restricted to the maximum value at which either alone just produces the maximum permitted deviation, then the total deviation of the main carrier by the sum and difference signals cannot exceed the permitted maximum. If we consider the two extreme cases where  $A = B = 1$ , and  $A = -B = 1$ , maximum deviation is produced by the sum and difference signals respectively. In the intermediate conditions the available deviation is shared between  $A + B$  and the  $A - B$  sidebands in a ratio determined by the relative phase of A and B.

In this respect the operation is quite different from, for example, the Crosby stereophonic system using a f.m. subcarrier. There, the difference-signal component of the multiplex waveform is a f.m. subcarrier of constant amplitude. Consequently the

proportions of the total deviation of the main carrier which are contributed by the sum and difference components of the multiplex waveform are fixed by the specification of the system. In this case it is the  $A + B$  and  $A - B$  signals that must be controlled to ensure that they do not exceed the specified levels.

**The Multiplex Waveform.**—Fig. 2 shows oscilloscope traces of the multiplex waveform of the Zenith-G.E. system with various conditions of modulation. In Figs. 2(a), (b) and (c) the 19 kc/s pilot frequency has been removed for the sake of clarity. Fig. 2(a) shows the waveform with a 1 kc/s tone applied to both the A and B inputs in parallel; since  $A = B$ , all the modulation is in the sum channel and the contribution of the difference channel is zero. The output thus contains only the original modulating frequency of 1 kc/s. In Fig. 2(b) the same 1 kc/s tone is fed to both A and B channels, but the phase of one input is reversed. We now have  $A = -B$ , so that all the modulation is in the difference channel and the output consists only of the upper and lower sidebands of the suppressed subcarrier, i.e. 37 kc/s and 39 kc/s. This is the characteristic picture of a suppressed subcarrier modulation envelope although, as the modulating frequency is not locked to the subcarrier frequency, the waveform within the envelope is not revealed and only appears as a blur. Fig. 2(c) shows the multiplex waveform with the input applied to the A channel alone; we have  $A = 1, B = 0$ , so that  $A + B = A - B$ , the sum and difference channels contributing equally to the output. The waveform is seen to be the sum of those shown in Figs. 2(a) and 2(b), reduced in amplitude by a factor of 2. These three waveforms illustrate the point mentioned earlier that, if the levels of the A and B inputs are controlled to the specified maximum value, the peak deviation of the main carrier will not exceed the permitted maximum. In all these cases the level of the modulating signal was the same and it can be seen that the peak-to-peak amplitude of the multiplex waveform, and hence the deviation of the transmitter, is constant.

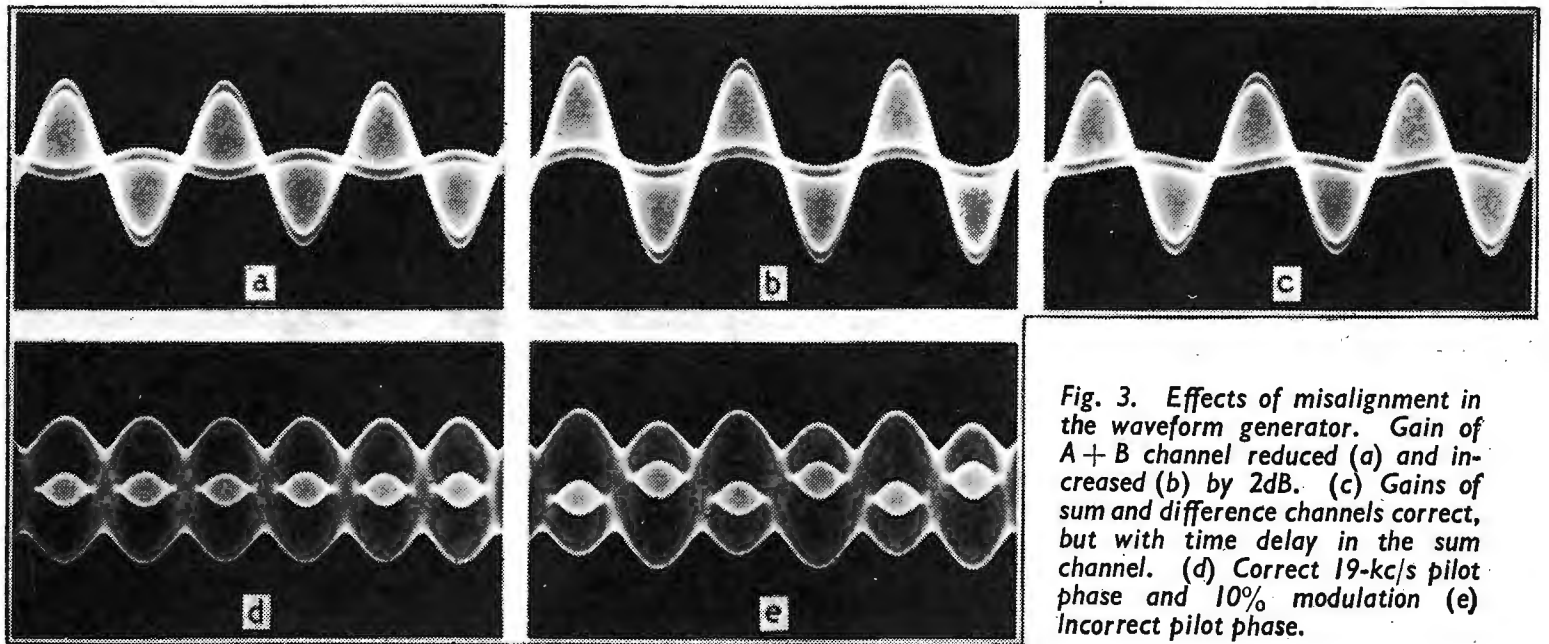


Fig. 3. Effects of misalignment in the waveform generator. Gain of A + B channel reduced (a) and increased (b) by 2dB. (c) Gains of sum and difference channels correct, but with time delay in the sum channel. (d) Correct 19-kc/s pilot phase and 10% modulation (e) Incorrect pilot phase.

Figs. 2(d), (e) and (f) are identical with 2(a), (b) and (c) but have the 19 kc/s pilot subcarrier added at an amplitude equal to 10% of that of the signal modulation.

The multiplex waveform has so far been considered as derived by adding an audio-frequency A + B signal to a suppressed-carrier amplitude-modulated A - B signal. It can be shown that this is identical with the waveform obtained by time-sequential switching, at the subcarrier frequency, between the A and B signals. This leads to the useful property that the waveform envelopes represent the A and B signals. This is well illustrated by the oscilloscope traces. In Fig. 2(a),  $A = B$  and the hypothetical switch is sampling two identical modulating waveforms. In Fig. 2(b),  $A = -B$  and the switch is sampling two sinusoids in opposite phase. In Fig. 2(c),  $A = 1$  and  $B = 0$ , the inner envelope along the base line representing the B channel input and the outer sinusoidal envelope the A channel input.

These two approaches to the composition of the multiplex waveform are reflected in the two techniques which can be used in the design of stereophonic receivers for the system. One method adds the regenerated 38 kc/s subcarrier to the A - B sidebands, demodulates the A - B signal, and combines A + B and A - B to produce A and B. The other uses the regenerated 38 kc/s to switch the multiplex waveform alternately into two separate a.f. channels which provide the A and B signals directly.

The foregoing discussion of the equivalence of the sequential switching technique has been rather over-simplified for the sake of brevity. The relative magnitudes of the sum and difference components (in the multiplexing process) and of the contributions of the sum and difference signals to the A and B outputs (on the receiving side) depend on the shape of the switching waveform and may require correction to restore the correct balance. For example, if a receiver uses square-wave switching, the contribution of the A - B signal to the output, relative to that of the A + B signal, is reduced by a factor of  $2/\pi$  with a consequent introduction of crosstalk. This can be corrected by cross-mixing between the A and B channels after the output of the switching circuit.

**Effects of Misalignment.**—Fig. 3(a), (b) and (c) represent the same modulating conditions as Fig. 2(f) but with deliberately introduced misalignment of the multiplexing apparatus. In Fig. 3(a) the gain of the A + B channel has been reduced by 2 dB, in Fig. 3(b) it has been increased by 2 dB, and in Fig. 3(c) the gains of the sum and difference channels are correct but their outputs have been de-phased by introducing a time delay in the sum channel. It will be seen that these misalignments all have the effect of introducing modulation on the previously straight centre base line of the modulation envelope; this corresponds to the introduction of crosstalk between the A and B channels. Furthermore, the magnitude of the crosstalk can be measured from the oscilloscope trace as the ratio between the peak-to-peak amplitudes of the outer and inner modulation envelopes.

One other parameter of the multiplex waveform, which has to be maintained within close tolerances, is the phase relationship between the 19 kc/s pilot and the 38 kc/s subcarrier. The phase of the transmitted pilot frequency determines the phase of the 38 kc/s subcarrier which is re-introduced in the receiver. Any appreciable error in the latter will cause a reduction in the A - B signal amplitude in the receiver, and hence crosstalk between the A and B channels, and may also give rise to non-linearity distortion. When the pilot frequency component of the transmitted multiplex waveform is correctly phased it appears on the oscilloscope trace as a "fringe" symmetrically disposed above and below the 38 kc/s modulation envelope. The original photograph from which Fig. 2(e) was prepared shows this quite plainly. Fig. 2(e) represents 100% modulation of the difference channel and for accurate indication of phase it is desirable to reduce the modulation depth and increase the oscilloscope gain. Fig. 3(d) shows the trace obtained with 10% modulation and the correct 19 kc/s pilot phase, while Fig. 3(e) represents incorrect pilot phase. It should be noted here, in case any reader is faced with the problem of aligning a Zenith-G.E. multiplex generator, that this method of checking by displaying the modulation envelope on an oscilloscope is in one sense ambiguous. If the pilot phase is rotated through  $180^\circ$ , the picture

(Continued on page 43)

shown in Fig. 3(e) will be produced at 0°, 90° and 180° relative to the correct phase condition. The 0° and 180° states are, of course, indistinguishable in operation and are both correct. Since the purpose of the pilot 19 kc/s subcarrier is to serve only as a phase reference for a waveform at twice its frequency, the reversal of phase is without significance. If, however, the 19 kc/s phase is 90° in error, the effect on a receiver is to produce the A signal from the B output and vice versa. The specification of the system states that, with a positive input to the A channel, the 19 kc/s and 38 kc/s waveforms should cross the zero axis simultaneously in the positive-going direction. Although a more refined measurement is therefore necessary to ensure that the pilot phase is in the correct quadrant initially, the system suggested above has been found of considerable value as a simple and rapid method for checking and correcting the small errors of phase caused by temperature variation and component drift.

**Performance:**—We commenced this article by stating four requirements which a stereophonic broadcasting system should satisfy. We have seen that the Zenith-G.E. system meets requirements one and two, that is it can be transmitted on a single channel and is compatible. With regard to the third condition, subjective tests have been carried out in which the listeners could switch at will between the audio output of a high-grade stereophonic tape recording, played directly into two wide-range loudspeakers, and the same programme after transmission through a complete Zenith-G.E. system, including a Band II signal generator and receiver. These tests demonstrated that the system can give excellent stereophonic reproduction, with relatively simple multiplex decoding circuits in the receiver, when the latter is presented with an adequate r.f. signal and no external interference.

As far as the fourth requirement is concerned, however, that the service area covered by a transmitter should not be unduly reduced by the conversion from monophonic to stereophonic broadcasting, it appears that some such reduction may be unavoidable. This arises from the fact that a multiplex stereophonic system is inherently more sensitive to noise and interference. Components in the region of 38 kc/s in the output of the receiver discriminator which, in a monophonic receiver, are above the audible frequency range, are detected in the subcarrier channel of a stereophonic receiver to produce an audible output. Thus listeners near the limit of the service area as defined for a monophonic service may find that the signal strength they receive is inadequate for an acceptable signal-to-noise ratio with stereophonic reception. The technical decision on the acceptability of the Zenith-G.E. system for broadcasting is now chiefly dependent on this question of coverage and what measures are possible to increase it.

There are three main sources of the type of noise and interference which must be considered:

- (i) Random hiss noise originating in the early circuits of the receiver;
- (ii) Impulsive noise of the kind radiated from car ignition systems and electric motors;
- (iii) Interference from other transmitters working on frequencies which are the same as, or closely adjacent to, that to which the receiver is tuned.

Considering first the effect on monophonic listeners with existing types of v.h.f., f.m. receiver; changing the existing broadcasting system to Zenith-G.E. would cause a reduction of signal-to-noise ratio, in respect of all the above sources of noise, of about 4 dB. It is often stated in the literature that this reduction is only 1 dB, based on the fact that the peak deviation of the sum signal is 90% of  $\pm 75$  kc/s, i.e., 1 dB less than that permitted in normal monophonic transmissions. Bearing in mind that in this system the individual A and B signals are restricted so that the total deviation due to the sum of  $A + B$  and  $A - B$  does not exceed 90% of 75 kc/s, the assumption of a 1 dB reduction in the average deviation due to the  $A + B$  signal alone would only hold good if the A and B inputs were always identical in amplitude and phase, in which case  $A - B$  would always be zero. In fact it has been found for typical stereophonic programmes that the average reduction in apparent deviation to the monophonic listener is about 4 dB, comprising 3 dB due to the lack of correlation between the A and B signals, plus 1 dB for the reduction of deviation required to accommodate the pilot signal.

In the case of stereophonic reception, the position is more complicated and the effect on each type of noise has to be considered separately. The signal-to-noise ratio in respect of receiver hiss is reduced by some 22 dB with reference to monophonic reception. This may appear to be a very considerable loss but in fact, even when using a receiver with a modest noise factor and a simple dipole aerial at roof level, it is not likely to produce a noticeable degradation except where the field strength is less than about 500  $\mu\text{V/m}$ . Below this level, satisfactory stereophonic reception would demand the use of a higher gain aerial mounted as high as possible and a receiver with a good noise factor.

Impulsive interference, particularly in urban areas and close to main roads, is likely to be troublesome even when the field is some millivolts per metre and the result of changing from the monophonic to the stereophonic system is to increase the audible effect of this type of noise by about 10 dB to 15 dB. In most situations impulsive interference can be reduced by the use of a higher and more directive aerial system and, where necessary, a further improvement might be obtainable by the use of an impulse limiter in the receiver.

We come now to interference from other transmitters. Where this is due to signals spaced in frequency from the wanted transmission by 200 kc/s or more, experiments using present-day receiver designs up to the f.m. discriminator have shown that the increase in the required protection ratio resulting from the change to stereophony is generally not more than 6 dB. This could be compensated without prejudicing stereophonic reproduction by an improvement in i.f. selectivity. Where the interference is due to an unwanted transmission at the same frequency, the additional protection required is of the same magnitude, about 6 dB. This is a comparatively small degradation; adequate amplitude limiting in the receiver would minimize it, and in the cases where such interference is troublesome a directional aerial may also be required. The most difficult case of interference with stereophonic transmission occurs where the interfering trans-

mission is offset by 100 kc/s; here the protection ratio required is 20 dB higher than with a monophonic service. The same palliative measures as were suggested to deal with co-channel interference would be of some assistance here but it is doubtful whether they would be a complete answer.

**Summing up:**—If the Zenith-G.E. system were adopted, listeners with existing monophonic v.h.f. receivers would receive a service which would be degraded in signal-to-noise ratio by about 4dB. In the great majority of cases this would not be noticeable. Listeners who wished to equip themselves for stereophonic reception would fall into two groups; those living within the inner zone of the service area could use receivers designed to the same standards as current monophonic models, with simple aerials, and would receive an adequate service. The one reservation in this case is that those situated close to sources of impulsive interference, busy roads or industrial equipment, may need more efficient

aerials or improved receivers. For a satisfactory stereophonic service in areas more remote from the transmitter, improved aerial systems and receivers specifically designed to minimize the various forms of interference and noise would in many cases be required, while in particularly difficult reception areas it seems probable that a satisfactory stereophonic service could not be provided.

The purpose of the field tests which are currently being conducted is to determine where the boundaries of these zones would fall, and hence the percentage of the population which could be adequately served, should the Zenith-G.E. system be adopted.

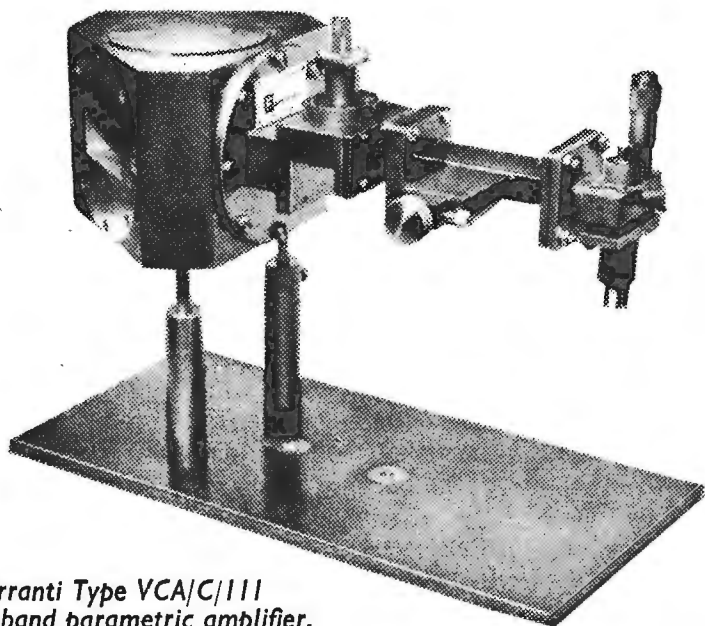
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1. Matras, J., "La Radiodiffusion Stéréophonique dans le Cadre Européen," *L'Onde Electrique*, Vol. 42, No. 420, p. 155, March 1962.
2. Saslaw, D., "What Hath F.C.C. Wrought?," *Audio*, Vol. 45, No. 6, p. 18, June 1961.

## MANUFACTURERS' PRODUCTS

### *C-Band Parametric Amplifier*

THE first of a range of parametric amplifiers, the type VCA/C/III, is announced by Ferranti. The amplifier has been designed for the frequency range 4-5 kMc/s (C-band) as a simple compact addition to a receiver to improve its noise figure. The circuitry is waveguide throughout, enabling it to be readily incorporated in an existing system. The parametric amplifier operates in a non-degenerate mode with an idler frequency of 6,000 Mc/s, a three-port circulator being used to separate input and output signals. A Ferranti ZC24B variable-capacity and diode is used as the active element, mounted across narrow height (2×0.1in) waveguide. The pump power is fed from number 16 waveguide to the diode through a resonant iris, and by careful design of the pump circuit the required pump power has been reduced to approximately 10mW at 10.6kMc/s. An overall noise figure of 3.5-4dB is obtained at 20dB

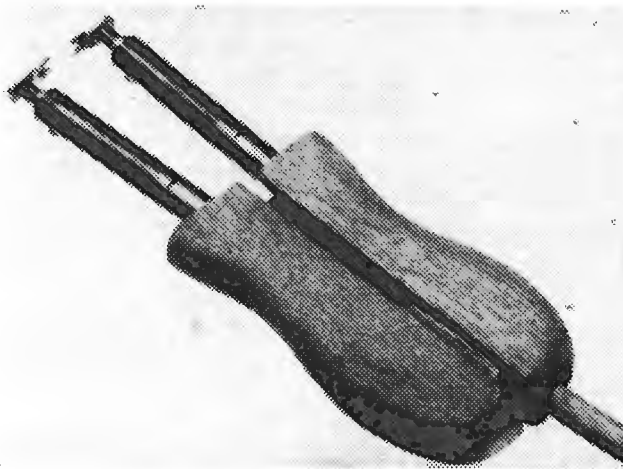


Ferranti Type VCA/C/III  
C-band parametric amplifier.

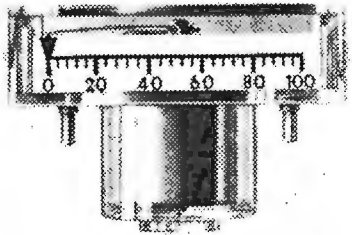
gain and 30Mc/s bandwidth. By adjustment of the pump frequency and diode bias potential (0-1V), a tuning range of 140Mc/s is possible from a single amplifier with noise figures less than 4dB; while a tuning range of 90Mc/s is possible by adjustment of the bias voltage alone. The type VCA/C/III C-Band parametric amplifier costs £600 and is available from Ferranti Ltd., of Hollinwood, Lancs.

### *Wire Stripper*

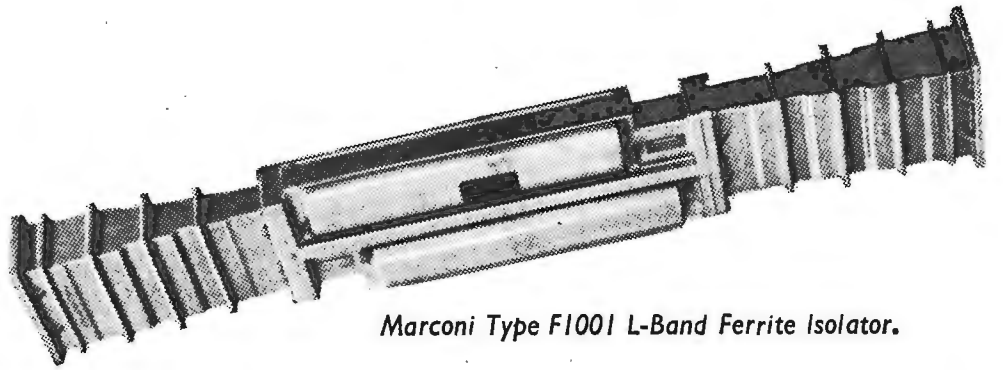
A NEW Labgear model is electrically heated for p.v.c. covered wire. In use the wire is gripped by two V-shaped prongs which heat the p.v.c. and allow it to be gently pulled off, leaving the conductor wires un-nicked and unbroken. This unit operates from a 12V supply and consumes 12W. A suitable mains transformer (which can feed up to 4 strippers) is available



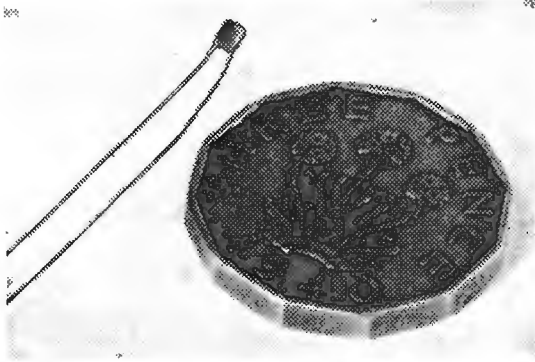
Labgear electrically heated wire stripper for p.v.c. covered wire.



Taylor model II meter. Case is transparent plastic, which allows external illumination of the scale.



Marconi Type F1001 L-Band Ferrite Isolator.



Gulton 300pF 50V ceramic capacitor, Type GL10.



Pensource pocket test oscillator. On-off switch is near the pocket clip.

for £2 5s and the wire stripper itself costs £2 15s. It is available from Labgear Ltd., of Cromwell Road, Cambridge.

### Miniature Meter

FOR use in equipment such as computers and multi-channel amplifiers, Taylor have introduced a new, miniature edgewise meter, the Model II. When mounted close together, the meters are unaffected by interfering fields from adjacent movements, and by nearby ferrous material, the basic movement being of the centre-pole design with its inherent shielding. The meter is available in sensitivities from  $50\mu\text{A}$  upwards and has a scale length of  $1\frac{1}{2}$ in, with a frontal area of  $1.68\text{in} \times 0.5\text{in}$ . A leaflet is obtainable from Taylor Electrical Instruments Ltd., Montrose Avenue, Slough.

### Miniature Capacitors

TWO new ranges of minute ceramic capacitors are announced by Gulton Industries (Britain) Ltd., of 52, Regent Street, Brighton 1, Sussex. The smaller of the two types, the 50V working Type GL10, is  $0.085\text{in}$  square and  $0.035\text{in}$  thick and is available in all 5% preferred values between 10pF and 300pF. Either axial or radial leads are provided. The 200V working P-600 range is  $0.27\text{in}$  square maximum and  $0.07\text{in}$  thick at the maximum capacitance of 10,000pF. Temperatures from  $-55^\circ\text{C}$  to  $85^\circ\text{C}$  change the capacitance less than 10%, and when encapsulation is increased, the capacitors can be used at  $150^\circ\text{C}$ .

### L-Band Ferrite Isolator

THE new Marconi type F1001 water-cooled isolator can handle mean powers as high as 15kW and peak powers of 6MW in the frequency range 1,200 to 1,400 Mc/s. The minimum reverse loss is 12dB, the forward loss at the most 0.4dB, and the v.s.w.r. better than 1.1 to 1. The use of special narrow waveguide has allowed

the magnets to be made lighter so that the whole isolator (together with the tapered sections for enabling it to be connected to standard No. 6 waveguide) weighs only 148lb. This type F1001 isolator is manufactured by Marconi's Wireless Telegraph Co., Ltd., of Chelmsford, Essex.

### Signal Injector

DESIGNED for the radio and television service engineer, the Pensource is a miniature test oscillator contained in a pocket case rather like a pen-torch. The instruments are potted transistor oscillators powered by 1.5V cells which, with normal use, last about five months. Each signal source operates on a fixed frequency—i.f. or audio—and gives about 0.5V output. It is intended to extend the range to cover signal frequencies for radio and television, and already a pulse unit is available for servicing industrial digital equipment. The Pensources cost £4 10s each, and are available from Electronic Machine Control Ltd., Mayday Road, Thornton Heath, Surrey.

### One-pack Sealing Compound

THE usual inconveniences of potting compounds—the necessity for curing at elevated temperatures and the use of two substances—are avoided in the Silcoset rubbers now marketed by I.C.I. The rubbers are supplied, in the form of paste, in either tubes or drums, and on exposure to atmospheric moisture cure to silicone rubber in a matter of a few hours with very little shrinkage. The pastes are ideal for potting circuits, sealing cable-ends and for any application in which thermal stability, water repulsion and good electrical properties are needed. Bonding to most surfaces is effected with the aid of a primer. Two types of paste are available—Types 150 and 151—the only difference being that Type 150 is red and Type 151 is greyish-white. A leaflet is available from Silicones Department, I.C.I. Nobel Division, Stevenston, Ayrshire.

# Aluminium Oxide as a Dielectric

DEVELOPMENT OF A NEW TYPE OF DRY CAPACITOR

By R. F. WILSON, B.Sc., A.R.C.S.

**R**ECENTLY developed anodization techniques have enabled aluminium oxide to be used as a *dry* dielectric under stresses nearing the intrinsic limit. This work, conducted at the Electrical Research Association, results from research done to improve the electrolytic capacitor, and has resulted in the development of a new lightweight capacitor having outstanding properties in which the electrolyte is dispensed with altogether. It will work on a.c. or d.c. up to peak voltages between 300 and 500 depending on the purity of the aluminium available, and combines the best properties of the conventional electrolytic capacitor and also those of the high-stability paper varieties.

Aluminium is a reactive metal of low atomic weight which is comparatively passive in air. This is due to the fact that the fresh metal surface rapidly develops a thin film of oxide which effectively seals off the metal from any further oxidation or other mild chemical attack.

This oxide possesses some unique properties, both

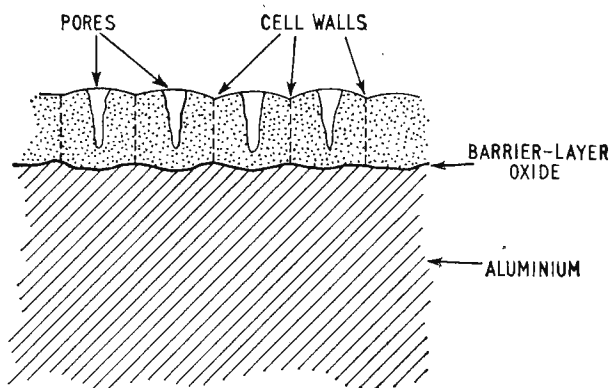


Fig. 1. Diagrammatic structure of porous oxide showing hexagonal cells and central pores.

mechanical and electrical, and has to some extent helped aluminium to fulfil so many useful roles in modern civilization.

Two varieties of oxide can be formed on aluminium by anodic means, depending on the conditions of formation. These are the porous films, and the non-porous or barrier-layer type oxides.

**The porous oxides** are used by industry for the protection of aluminium, and being porous are capable of being dyed. Sealing has to be carried out and this is achieved by boiling in water to convert some of the oxide into the hydroxide (in the boehmite form), which, occupying a greater volume than the oxide, fills up the pores.

Porous films are obtained by anodizing in strong acids such as phosphoric, chromic, sulphuric and

oxalic, and can be formed on alloys of aluminium. The amount of oxide formed in any of these electrolytes depends on Faraday's Law, i.e. is proportional to number of coulombs passed, but the final quantity of oxide deposited as a film on the aluminium will be a balance between deposition and dissolution by the electrolyte. The rate of dissolution depends on which of the above acids is used, its concentration and the temperature of the bath. By suitable control of these variables it is possible to make the rate of formation of oxide equal the rate of dissolution, with the result that electropolishing takes place. For normal purposes, of course, a maximum possible thickness of oxide is desirable for a given time in an anodizing bath: the dissolution rate must then be at a minimum.

When viewed under the electron microscope, the porous type of anodic oxide is found to be built up of regular hexagonal cells each with a central pore<sup>1</sup> (see Fig. 1).

Between the base of the pore and the aluminium surface is a thin layer of denser, barrier-layer type oxide, the thickness of which is determined by the formation voltage. Also voltage dependent, but with a logarithmic relationship, is the volume of the pores. The cell size on the other hand appears to bear a linear relation to the formation voltage for a given electrolyte (see Figs. 2 and 3). For any particular use it is of importance to ensure that the pore and cell dimensions in the oxide are of an optimum size. Thus for hardness and abrasion resistance, the cell size should be as large as possible, with small pores, whereas if electroplating is to be carried out over the anodized layer, large pores are desirable. The choice of electrolyte is also of importance here, for the more active the acid, the larger will be the pores for any given anodizing voltage.

**The non-porous or barrier-layer oxide** is in complete contrast to the type already described and has fewer industrial applications: it can be formed only on high-purity aluminium, whereas the porous oxide can be produced on aluminium alloys. The barrier-layer oxide is a good dielectric, and is produced with electrolytes of a non-corrosive nature, for example boric, citric or tartaric acids.

The thickness of film depends entirely on the voltage applied, the electrolyte having no appreciable solvent action on it. To produce a film 1 micron ( $10^{-3}$ mm) thick it is necessary to anodize at 750 volts. It has not been found practical to obtain films with formation voltages less than about 200 volts

<sup>1</sup> Keller, Hunter and Robinson, "Structural Features of Oxide Coatings on Aluminium," *J. Electrochemical Soc.*, Vol. 100, 1953, p. 411.

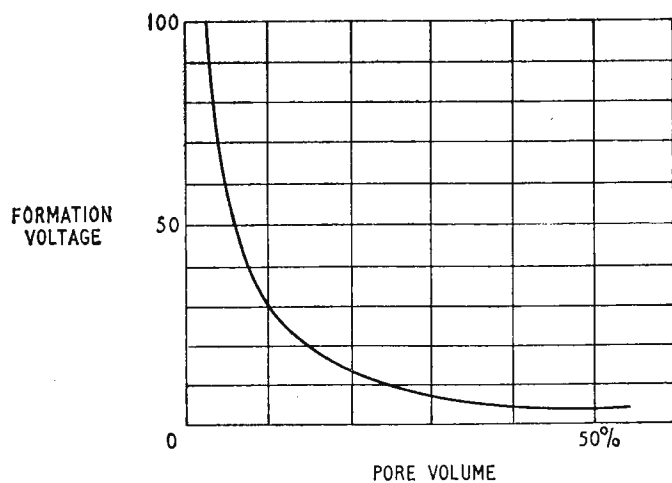


Fig. 2. Effect of formation voltage on pore size (per cent of cell size).

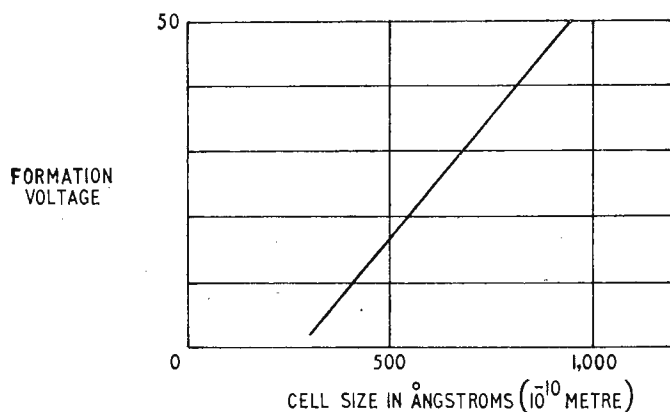


Fig. 3. Effect of formation voltage on cell size.

when a simple acid electrolyte is used, mainly because it is not conductive enough. High conductivities can be obtained by the addition of a small percentage of sodium or ammonium borate, when low-voltage films can be successfully formed. Similarly, it is not practical to produce films thicker than about  $1\frac{1}{2}$  microns, since the film either breaks down locally ("scintillation") if the conductivity of the electrolyte is normal, or forms badly if the conductivity is reduced sufficiently to avoid scintillation.

In addition (and of great importance, especially at higher voltages) is the need for extremely pure electrolytes. It has been found that a chloride ion con-

centration exceeding one part in  $10^7$ , for instance, is detrimental and causes a poorly formed oxide. Impurities probably also cause scintillation, which damages the film.

Non-porous oxides, unlike the porous variety which is formed at constant current, are formed with an initially very high current density, which rapidly falls off. Non-porous oxide formation thus needs special techniques whereby these high current densities can be supplied without the use of large d.c. generators.

Commercially, this involves the use of winding gear to pull the aluminium foil into the electrolyte at a constant rate. In this way the high current density associated with the unanodized aluminium is kept to a reasonable value, as only the small area at the point of immersion is concerned, the portion already immersed having formed a resistive layer of oxide which cuts down the current (see Fig. 4). On a laboratory scale, where continuous anodization is not desired and only comparatively short lengths of foil are required to be anodized, a plant has been developed where the electrolyte is made to rise up a long cylinder containing the anode and cathode assembly. This system has the advantage of being capable of very accurate control, which is important where evenness of deposition is concerned (see Fig. 5). It has been shown experimentally that a high initial current density is desirable for the production of good oxide. If the voltage is applied gradually to keep the current low, with the foil totally immersed in the electrolyte, a poor quality oxide results; hence apparatus such as that shown in Figs. 4 and 5 is necessary.

To summarize the properties of the above varieties of oxide: the porous oxide is good mechanically, and has the advantage that it can be readily formed to any desired thickness, while the barrier type oxide, being free of pores, has fair electrical properties. It would therefore be useful if the two properties could be combined in some way. It is obvious that the two oxides could not be produced in one operation owing to the very different nature of their electrolytes and formation. Calculation from experiment gave the conditions necessary to produce films of porous and of non-porous oxides of equal thickness (normally 1 micron) on a foil of given surface area. The idea was to begin anodization with a porous oxide of the desired thickness, and

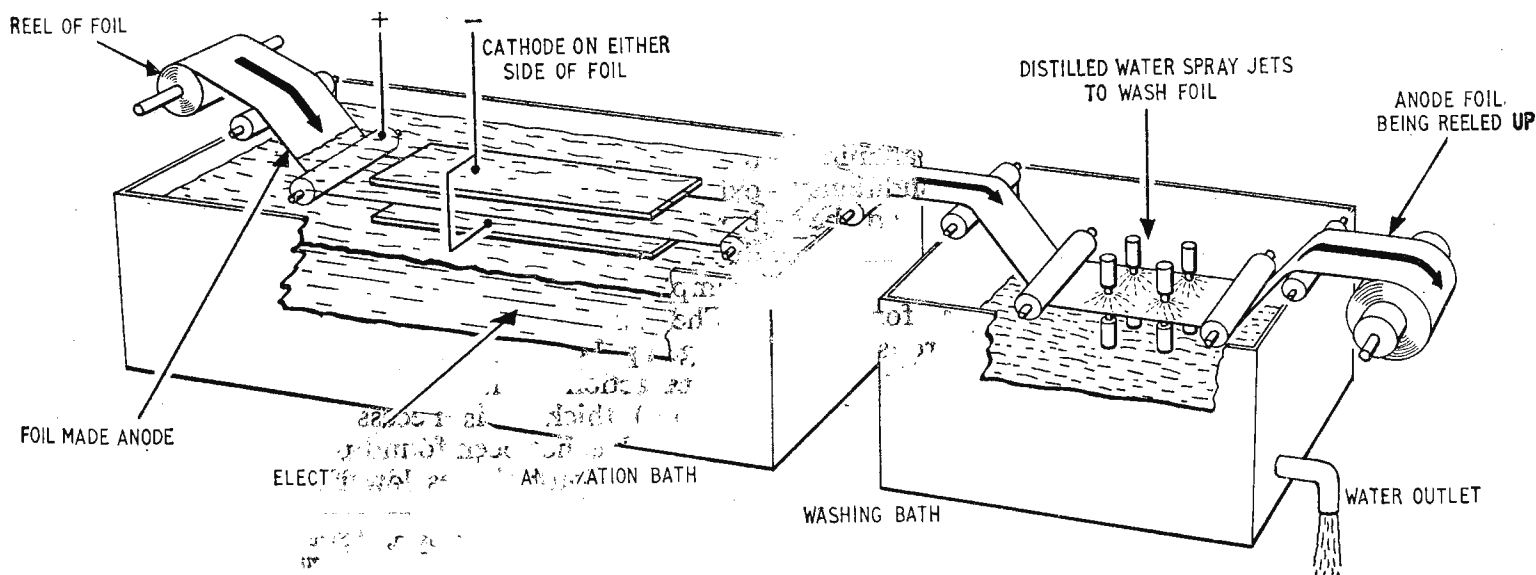
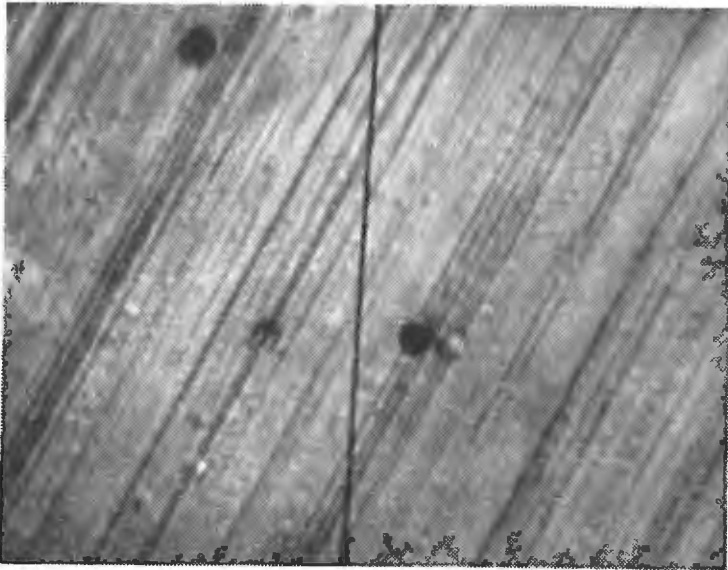
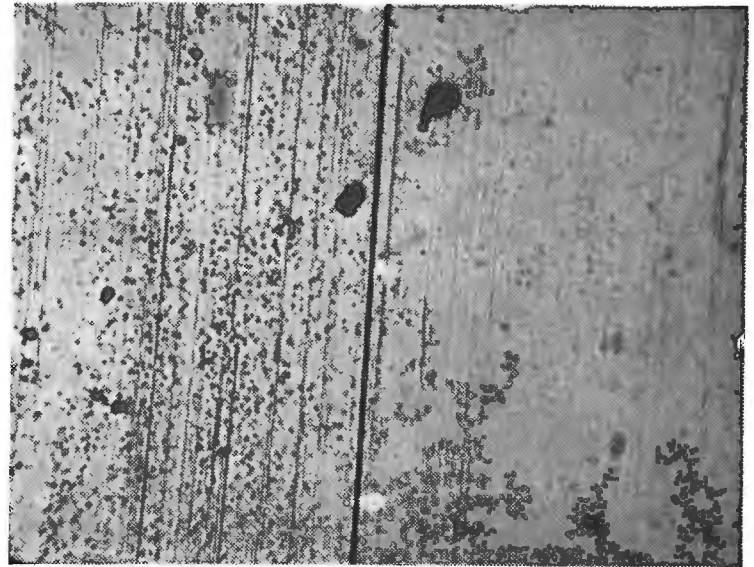


Fig. 4. Diagrammatic layout of commercial anodization plant.



Photomicrograph of freshly rolled aluminium surface showing bumps due to embedded particles ( $\times 400$ ).



Photomicrograph of oxide taken with transmitted light showing opaque particles exposed during anodization ( $\times 100$ ).

then to follow this by a second anodization in the barrier-layer electrolyte, in the hope that the pores would be filled by the latter type of oxide. However, it was at first found that the barrier-layer oxide would not form on a previously formed oxide. Investigation showed that the electrolytes necessary for non-porous films were intolerant to even very small concentrations of other electrolytes. Measurement of the pore volume of oxides formed in such electrolytes as phosphoric acid and chromic acid indicated that enough of these electrolytes could be trapped in the pores to produce higher concentrations than 1 part in  $10^6$ .

A search was therefore made for a compatible pair of electrolytes.

Since oxalic acid is an organic acid and therefore less reactive than some of the other electrolytes forming porous films, it was decided to try it in conjunction with boric acid as the barrier-layer

electrolyte. In addition, oxalic acid is volatilized quite readily, so it could be removed by heating. It was found that concentrations of oxalic acid up to about 5 parts per million could be tolerated, which was a great deal more than would be expected to be trapped in the pores. Also the pore size is less for a given formation voltage in oxalic acid than in the other acids, and this helps to cut down the amount of electrolyte transferred from one bath to another.

### Practical Aspects

**Cleaning Techniques:** Since boric and oxalic acid electrolytes proved to be perfectly compatible, a systematic study of the composite oxide was started. Standards of breakdown strength for the oxide were set up and foils were anodized under varying conditions to see if improvements could be made. Initially, industrial cleaning methods were used to free the foil of its surface impurities. The latter were found to be due to two things: (1) a thin film of oil left from the rolling process; (2) grease films derived from the air (depending on the movement of air this could contaminate a clean foil in a matter of hours). Either of these could upset anodization and result in much reduced breakdown strength.

Amongst the cleaning methods tried were normal degreasing baths using detergents, acid and alkaline etching baths, hydrogen peroxide, and ultrasonic agitation. The detergents did not remove all surface impurities, probably because the foils could not be scrubbed but only dipped in them. Only when used in conjunction with ultrasonics were they of any use, and then due to the thinness of the foil the cavitation effect blew neat holes across the foils at half wavelength intervals!

The etching baths, while being better than no cleaning at all, proved unsatisfactory as they roughened the surface of the foil which, it was found later, should be as smooth as possible.

The only really satisfactory method of cleaning proved to be a dip in 30% hydrogen peroxide maintained at  $60^{\circ}\text{C}$ . This degreases the metal without attacking it chemically, and also leaves no harmful by-products which could contaminate the anodiza-

(Continued on page 49)

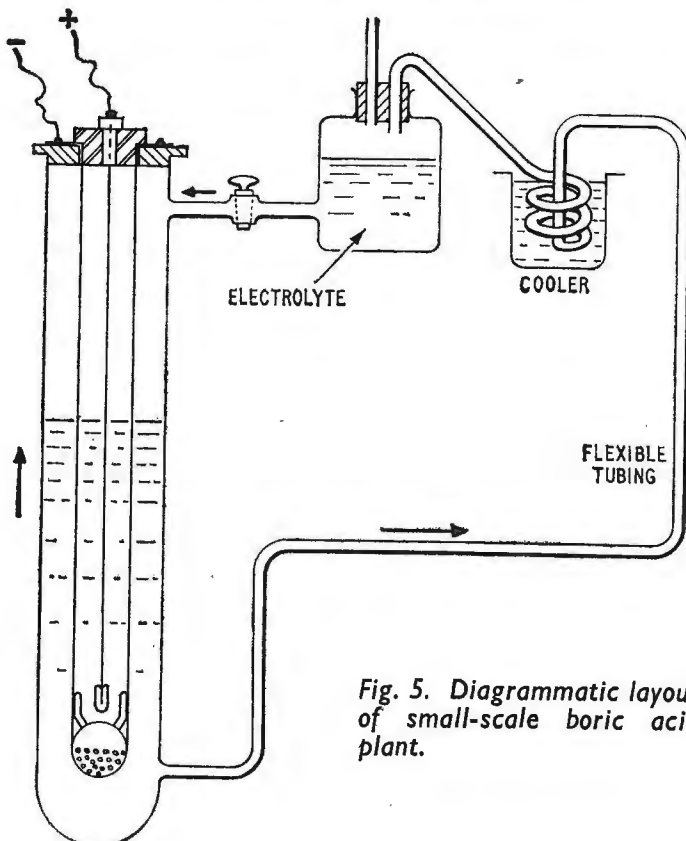


Fig. 5. Diagrammatic layout of small-scale boric acid plant.



tion baths. The test applied to find out if the foil is clean is to spray it with water and see if it wets perfectly.

**Importance of Purity in the Metal:** While the aluminium is being rolled to its final thickness—in the case of a 10-micron foil this may involve several rollings—it is liable to suffer damage from two sources during the process. The first is rolled-in dust and metallic particles from the rollers. These are of the order of 1 micron in size and, as shown in the accompanying photomicrograph, are generally embedded about  $\frac{1}{2}$  micron from the surface with aluminum streaked above them. When the foil is subsequently anodized the embedded particles will either react with the electrolyte and so upset the formation of oxide, or will remain passive and stop the oxide forming in that area. The other photograph is of oxide magnified 100 times and taken with transmitted light: opaque particles have been exposed during anodization and can be seen embedded in the oxide film.

The second source of damage occurs during the annealing process. From recent research it has been found that if aluminium is heated in the presence of water vapour, hydrogen is accumulated at grain boundaries. This causes appreciable expansion of the metal and, when it is subsequently anodized, results in potentially weak areas which will readily break down under stress.

**Purity of the Electrolytes:** It has already been mentioned that it is of great importance that the electrolytes be kept as pure as possible. As anodization in the open air invites contamination, a plant was built where the foil could be anodized in an enclosure. It consists of a Perspex box designed to contain the anode, which can be lowered into any one of four glass cylinders. These contain:—

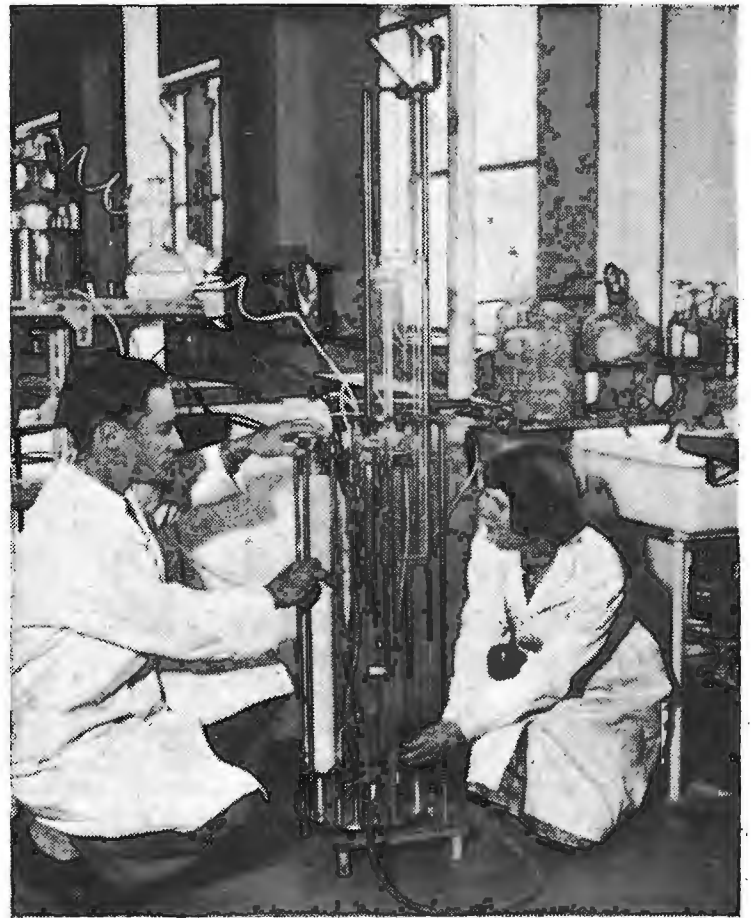
- (1) The pre-treatment bath containing hydrogen peroxide;
- (2) The first anodization bath containing oxalic acid. To ensure an even oxide deposit the electrolyte is circulated continuously.
- (3) The boric acid plant. Here the non-porous electrolyte is allowed to rise up the cylinder at a carefully controlled rate. The method of doing this is shown diagrammatically in Fig. 5. Both the anodization cylinders contain U-shaped cathodes held at the top by Perspex caps.
- (4) The washing cylinder. Near the top is arranged a series of fine glass jets through which distilled water is made to spray on to the foil: the latter is lowered into the tube to be washed between successive operations.

### A New Capacitor

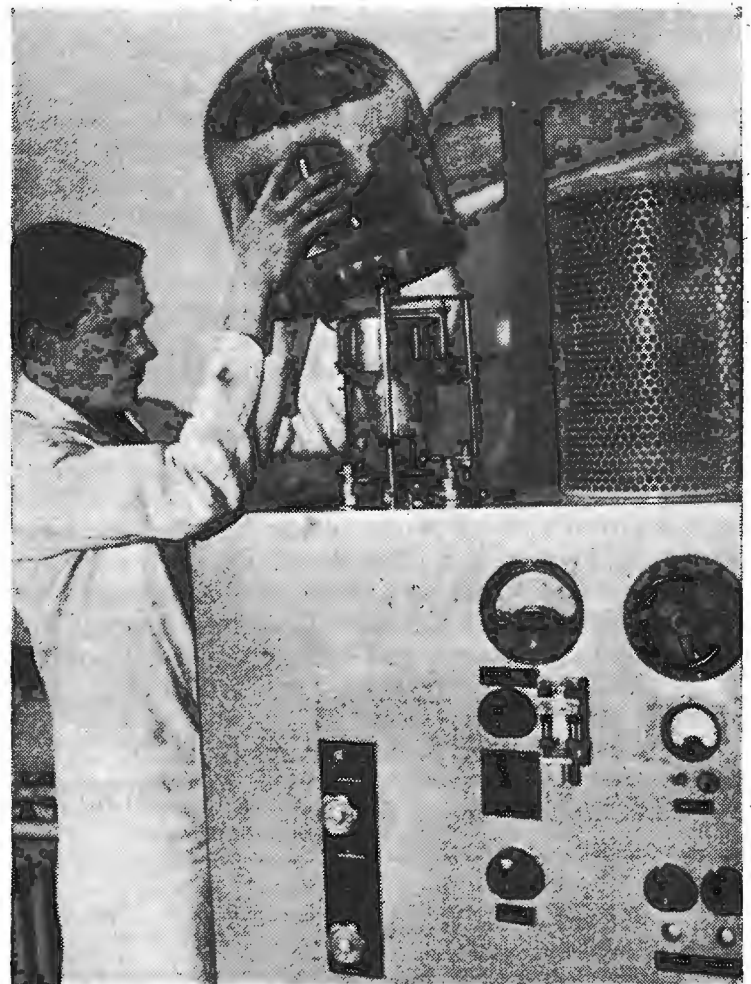
Using the above techniques, it was possible to produce oxide films with much better electrical properties than any previously available. Table I compares the composite oxide and the two parent oxides in regard to their electrical resistances.

Having a reliable dielectric, it was now possible to attempt the production of a dry capacitor. One requirement is a counterelectrode in intimate contact with the dielectric, and thin enough to burn out locally at the site of a short-circuit.

These requirements were met by evaporating an aluminium counterelectrode on to the dielectric in



*Experimental anodization plant. The Perspex box used for housing the anode foil can be seen half lowered over one of the four cylinders.*



*Vacuum plant. The operator is raising the bell jar from the base plate. Inside can be seen the circular framework around which the foil is wrapped, and various electrode supports.*

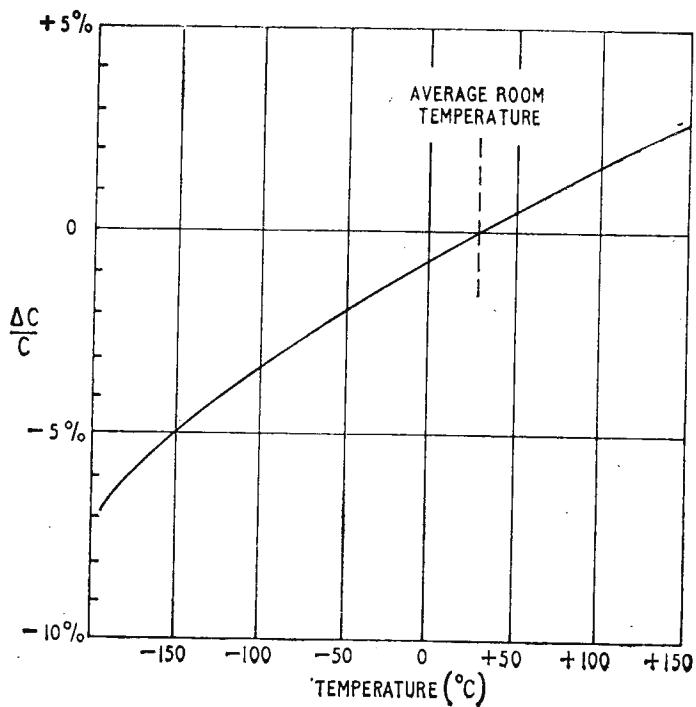


Fig. 6. Relation between capacitance and temperature.

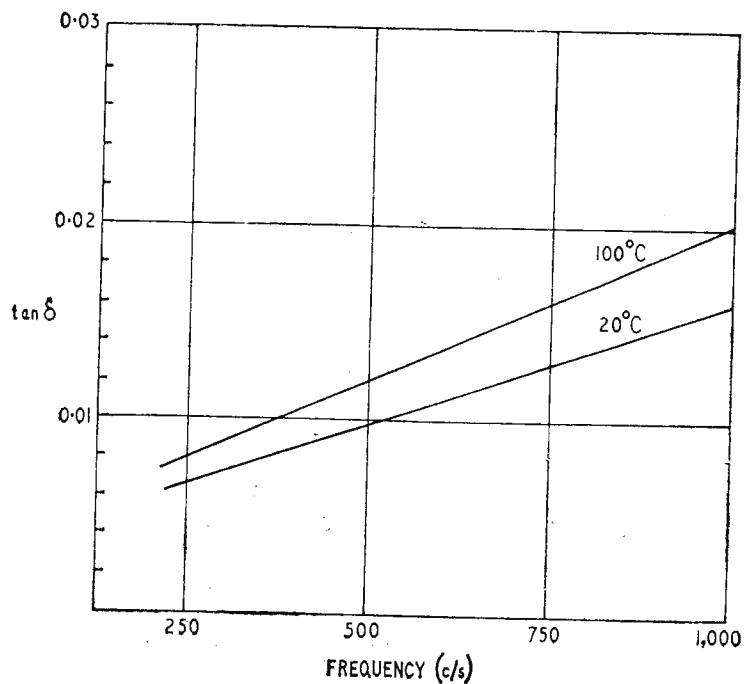


Fig. 7. Relation between frequency and  $\tan \delta$ .

a vacuum. The apparatus includes a circular framework around which the foil is wrapped, and mechanism to control the vertical movement of a mask and rotation of the foil on its framework. Two sets of filaments are used, one to deposit the counter-electrode to the required thickness, while the second, which is incorporated with the mask, is later raised to deposit two thick bands. These are registered on corresponding bands of a thermosetting resin which has previously been applied at the sites where terminal connections are required.

**Properties:** Before the completed capacitor is wound into a cylindrical form it must be cleared from faults at weak points in the oxide film. For this purpose it is mounted flat in an oven maintained at 60°C to keep the foil dry during these preliminary tests. Although the composite oxide is much less sensitive to changes of humidity than either the porous or non-porous oxides separately, its resistance does vary slightly with humidity.

Inevitable handling produces slight damage to the brittle oxide, and in most cases the capacitor will need initial clearing. Up to a certain voltage it will have a fairly high leakage current through defective spots in the oxide. These will clear at some sufficiently high voltage by virtue of the fact that the heat generated by the current will oxidize the counter-electrode locally and so isolate the damaged area. After initial clearing the new capacitor is taken up to its working voltage and left for a few minutes.

TABLE I  
Resistance of 1-micron  $Al_2O_3$  films.

Type of anodization	Resistance of oxide in megohms/cm <sup>2</sup>	
	In room atmosphere.	Dried.
Porous oxide (oxalic acid)	250	6000
Non-porous oxide (boric acid)	$1.6 \times 10^4$	$5 \times 10^5$
Composite oxide	$10^6$	$3 \times 10^6$

It is then discharged and its capacitance and power factor measured. This is best done with a Schering bridge.

The capacitor is now ready for winding. Most of the prototypes have been wound on to small glass formers. An oxide layer 1 micron thick can be bent either in tension or compression without damage provided the radius of curvature is not less than 1 inch. It will, however, stand bending in compression down to a radius of  $\frac{1}{4}$  in so long as the foil is not afterwards straightened. If it is, severe cracking of the oxide occurs. Contact with the counter-electrode has presented a number of problems owing to the fact that it is necessarily so thin. Originally thin tinfoil strips were merely laid in contact with the thick bands of aluminium previously deposited, but with this construction life tests over a period of months showed that the power factor varied considerably, due to gradual development of poor contact with the counterelectrode. An attempt was made to use gold on the thick bands to prevent oxidation of the aluminium, causing intermittent contact, but this was not wholly satisfactory. A better method has been found which involves the use of aluminium contacts stuck on to the thick bands by means of silver-impregnated epoxy resin. The latter has the effect of a conductive glue and seems to work very well. The rolled capacitor is once again subjected to its working voltage to clear it of any faults produced by damage to the oxide in the winding process.

Storage of the completed capacitor produces no appreciable deterioration. This is an advantage over the electrolytic capacitor which often deteriorates so badly after storage that the oxide needs reforming. Temperature is found to have little effect, and the capacitor will work normally from liquid air conditions up to 120°C. Fig. 6 shows a plot of capacitance against temperature, and from this it can be seen that between these temperatures there is only about 12% change in capacitance. Capacitors with an oxide film 1 micron thick have a capacitance of  $0.006 \mu F/cm^2$  with a working voltage between 350 and 500 volts d.c. or a.c. peak, depending upon the purity of the aluminium foil. They will work on

a.c. due to the fact that no electrolyte is present once formation is complete and so, unlike the electrolytic capacitor, they are not polarized.

In Fig. 7 the loss angle of a 1  $\mu$ F capacitor is plotted against frequency for two values of temperature. Also, unlike the electrolytic capacitor, the loss angle falls with decreasing temperature, and at  $-180^{\circ}\text{C}$  is about half that at room temperature. Due to the resistance of the thin evaporated counter-electrode, the loss angle increases at higher frequencies, so for high frequency working it is desirable

to have as many areas of contact with the counter-electrode as possible.

The insulation resistance of the oxide is exceptionally good, and is comparable with the best paper capacitors.

Life tests have been carried out for nearly a year under working voltages and elevated temperature conditions ( $103^{\circ}\text{C}$ ) and results have been very satisfactory. It is hoped that the dry capacitor with its great improvements over the parent electrolytic, can soon be on the market. Samples have been provided for commercial evaluation.

## PHYSICAL SOCIETY EXHIBITION

### RECORD NUMBER OF PARTICIPANTS

STILL known colloquially as the Physical Society Exhibition, the Annual Exhibition of the Institute of Physics and the Physical Society—to give it its full and rather cumbersome title—opens at the Royal Horticultural Society's Halls, Westminster, on January 14th for four days. In pursuance of the policy of "preserving and enhancing the unique nature of these annual exhibitions as scientific occasions rather than as opportunities for displays of ordinary commercial products" the amalgamated Institute and Society has modified the system of selection of exhibits for this the 47th of the series of exhibitions. From each exhibitor's proposed exhibits has been selected "those instruments, pieces of apparatus and materials which physicists use or are likely to use in the practice of their profession and which have been developed during the past three years."

As a result of this stricter selection procedure it has been possible to increase the number of manufacturers taking part to 118, compared with last year's 91. The exhibits from Government research establishments and university or college laboratories, plus a collective display on behalf of publishers of scientific books, brings the total to 145 against last year's 137. The complete list of exhibitors is given below.

The exhibition will be open each day from 10.0 to 7.0 but on the second day admission during the morning is restricted to members of the Institute and Society. Admission is by ticket only, applications for which should be made to exhibitors or the organizers at 47 Belgrave Square, London, S.W.1. Applicants are asked to enclose a stamped addressed envelope to accommodate the tickets ( $4\frac{1}{2} \times 3$ in). The exhibition Handbook, which is a useful book of reference, is obtainable from the organizers price 6s, plus 2s postage.

This year's exhibition lectures are:—

"Optical Research and the Solid State Laser" by Dr. J. M. Burch (15th at 3.0).

"Applications of Ultrasonics" by C. F. Brockelsby (16th at 5.45).

"The Experimental Investigation of Space" by J. A. Ratcliffe (17th at 5.45).

A.M.F., British Research Lab.  
A.W.R.E.  
Admiralty, Dept. of Res. & Dev.  
Advance Components  
Associated Electrical Industries  
Aveley Electric  
Avo

B.S.I.R.A.  
Baker Instruments  
Baldwin Instrument Co.

Barr & Stroud  
Beck, R. & J.  
Bellingham & Stanley  
Birkbeck College  
Birmingham University  
Bristol University  
British Aircraft Corporation  
British Electric Resistance Co.  
British Iron & Steel Res. Assoc.  
British Oxygen Co.  
Burndept

C.N.S. Instruments  
Cambridge Instrument Co.  
Cawkell Research & Electronics  
Central Office of Information  
Consolidated Electrodynamics  
Cooke, Troughton & Simms  
Coulter Electronics  
Crystal Structures

D.S.I.R.  
Darenth Weighing Equipment  
Dawe Instruments  
Decca Radar  
Devices  
Digital Measurements  
Distillers Co.  
Dynatron Radio

E.M.I. Electronics  
Edwards High Vacuum  
Ekco Electronics  
Electrical Remote Control Co.  
Electron Physical Instruments  
Electronic Instruments  
Elga Products  
Elliott Brothers  
Elliott-Litton  
English Electric Valve Co.  
Epsilon  
Evans Electro Selenium

Farol Research Laboratories  
Feedback  
Fenlow Electronics  
Fielden Research

General Electric Co.  
Genevac  
Glasgow University  
Gulston Industries

Hatfield Instruments  
Hilger & Watts

I.C.T. (Engineering)  
Instron  
Isotope Developments

Johnson Matthey & Co.  
Joyce Loebel

Kasama Electronics  
Kent, George  
King's College, Newcastle

Labgear  
Leeds University  
Levell Electronics  
Lewis, H. K., & Co.  
Locarte Co.  
Lucas, Joseph

M.O. Valve Co.  
Marconi's W/T Co.  
Mechanism  
Megatron  
Mervyn Instruments  
Meterflow  
Microwave & Semiconductor Dev.  
Microwave Instruments

Ministry of Aviation  
Ministry of Power  
Muirhead & Co.  
Mullard

N.G.N. Electrical  
Nagard  
Nash & Thompson  
National Research Dev. Corp.  
Newport Instruments  
Nuclear Enterprises

Optical Works  
Ottway & Co.

Panax Equipment  
Paton Hawksley Laboratories  
Perkin-Elmer  
Planer, G. V.  
Plessey Co.  
Post Office Research Station  
Prior, W. R.  
Pye, W. G., & Co.

R.P.R. Patents  
Racal Instruments  
Reading University  
Rotax Ltd.  
Royal College of Surgeons  
Royal Meteorological Society  
Royal Military Col. of Science  
Royston Instruments

S.E. Laboratories  
Sanders, W. H. (Electronics)  
Sangamo Weston  
Science Museum  
Semiconductor Thermoelements  
Servomex Controls  
Shandon Scientific Co.  
Smith Industrial Division  
Sogenique (Electronics)  
Southampton University  
Southern Instruments  
Standard Telephone & Cables  
Stanley, W. F.  
Stanton Instruments  
Stephen, R. A., & Co.  
Sunbury Glass Works

Techne (Cambridge)  
Telford Products  
Thermal Syndicate  
Thompson, J. Langham  
Tinsley, H., & Co.  
Transitron Electronics  
20th Century Electronics

U.K. Atomic Energy Authority  
Ultrasonoscope Co.  
Unicam Instruments  
University College, London  
University Col. Hospital Med. Sch

Venner Electronics  
Vinten

Watson, W., & Sons  
Wayne Kerr Laboratories  
Wray (Optical Works)



By "FREE GRID"

## *E.M.F. or Tentance?*

DESPITE the remarks of Karl H. Olbricht in his letter to the editor (page 31), I still think "electromotive force" to be a clumsy expression, although I agree with what he says about its aptness. But surely an equally good case could be made out for using "hydromotive force" to describe the *causa operandi* of the Niagara Falls or the ordinary domestic water tap. However, I prefer the word "gravity" or, as I suppose I ought to say, "gravitance."

Unfortunately, Herr Olbricht's suggested word "tendance" is already to be found in the works of Milton and Spenser with the meaning of "tending" or "taking care of." We need not, however, discard his etymological idea entirely, but can, by a bit of fiddling, improve upon it by retaining the "t" in front of the suffix, absence of which, he thinks, might prevent "tendance" becoming a "pop" word.

All we need do is to substitute a "t" for the "d," and so arrive at the word "tentance." This word is built up from *tentus*, the past participle of the Latin verb *tendo*, just as the word "inductance" is derived from *inductus*, the past participle of the verb *induco*.

I can almost hear the typewriters tapping and the pens spluttering to remind me that the past participle of *tendo* is not *tentus* but *tensus*, which gives us words like tense and tension. Such is, indeed, the case, but if the tappers and splutterers will take down their very heaviest Latin dictionaries, in place of the simplified versions intended for tiny tots and teenagers, they will find that *tentus* is a valid variant used by many Latin authors, which gives us tent, attention, etc.

Thus the famous equation becomes:—

$$\text{Intensitance} = \frac{\text{Tentance}}{\text{Resistance}}$$

## "Amately" Activities

THE International Radio Communications Exhibition ("Radio Hobbies" to you) held last November is ancient history now, and so it may seem a bit out of place for me to refer to it. I cannot, however, refrain from adding my meed of appreciation in respect of the exhibit staged by the British Amateur Television Club. I should, of course, have written this in the

December issue, but unfortunately the editor's space, like that of the late Sir James Jeans and some of his contemporaries, is finite.

I was truly amazed at the steadiness and good quality of these demonstrations by amateurs having very limited resources compared with those available to the engineers of the B.B.C. and I.T.A., with the prodigal finances at their disposal.

I should also like to pay a tribute to the patience with which certain technical details were explained to me by the budding bod who took me under his wing. No doubt some of my subsequent questions must have reminded him of the old lady who, after having had the mechanism of a car carefully explained to her, asked where the boiler was.

I feel sure that in the years to come we shall see many members of this "Amately" Club in the ranks of the professional television organizations. I wonder if it would be a good idea if the engineering chiefs of the B.B.C. and I.T.A. insisted that would-be recruits to their staffs should show proof that they had been active members of the club for a year or so.

## *Emergency TV Sets*

IN spite of the immense popularity of television today, with families planning their viewing of favoured regular programmes for weeks ahead, it is surprising how few households possess a second TV set for use in an emergency. It must often happen that great vexation of spirit is caused by the sudden failure of a set just as an eagerly awaited programme is about to begin.

Things are quite different in the realm of sound radio, because very few families lack a second receiver even if it be only a tiny transistor portable. I myself have found it quite impossible to escape Mrs. Dale by a carefully planned bit of sabotage, because Mrs. Free Grid keeps a transistor set hidden in a place which I have never been able to discover, despite the recent revelations of some of the old pupils of a famous girls' school, about where they used to keep their forbidden "make-up" kits.

It is true that when one hears, for instance, Sibelius's *Finlandia* played by a world-famous orchestra, and reproduced by a flyweight transistor set, it seems to lack meat and backbone, but it is at least recognizable.

It is not so strange as it might

seem at first that the average family does not possess a second television set of even the humblest type, because they are expensive things. What is strange is that manufacturers do not seem to have bothered to design and produce a relatively inexpensive emergency TV receiver, devoid of all frills, and using a comparatively small, and, therefore, not-too-expensive, tube.

Such a set would be invaluable to any ordinary family of viewers, and beyond all price to the average TV-transfixed teenager.

There no doubt exist services akin to the A.A. or R.A.C. for the motorist to whom a desperate call for help can be made when a receiver breaks down at a crucial moment; even so the help would inevitably arrive too late for that particular programme.

I do suggest, therefore, that manufacturers get busy with the design of a small emergency set. Even a ship with its elaborate main radio installation, also carries a comparatively simple emergency one. No doubt it will be said that people wouldn't buy them even if such sets were manufactured. I can hardly believe that, because it only needs a glance at some of the fatuous TV adverts to make it clear that people can be persuaded to buy anything; after all, those who sponsor the adverts aren't the sort of people to pay out substantial sums of money for no results.

## *Why "Y"?*

SOME time ago, I asked in these columns if any of you could tell me why it is that in Algebra—which is such a basic tool in the calculations of radio engineers—the letter  $x$  is used for the unknown quantity. It has been adopted in the term "X-rays," because these radiations were very much of an unknown quantity when first discovered. It was finally pointed out to me that  $x$  is the initial letter of the Greek neuter adjective *xenon* when transliterated into the Latin alphabet which we and most other European nationalities use. This word means "strange" or "a strange thing," and anything "strange" is more or less unknown.

At the time I forgot to ask why  $y$  is used as the symbol for the second unknown quantity in, for instance, a simultaneous equation. Can it be that  $y$  was adopted because it happened to be the letter following  $x$  in our alphabet, or is there some other Greek (or what have you?) word which also means unknown.

It has been suggested to me that the Greek word *hynaleos* which means, among other things, "ignorance," may be the key to the problem. The reason is, so I am told, that the Greeks as a people have always been as much given to dropping their aitches as some of us so that often the word is rendered as *ypnaleos* with of course *y* as the initial letter. Frankly, although I have checked this theory and found it not devoid of truth, I don't think it is the real explanation at all for the use of *y* as second fiddle to *x* and that is why I seek your help.

However, what I am most anxious to know is why the Greek letter  $\lambda$  is used to indicate wavelength. Was it just because  $\lambda$  happened to be not in use for anything else when a symbol for wavelength was needed? Maybe there is some explanation on a par with the use of  $\pi$  as the symbol for the number which enables us to square the circle.  $\pi$  was adopted because it is the initial letter of the Greek word *plateia* which means "square."

### CULOM

RECENTLY while travelling in one of the London tubes I saw an advertising placard carrying the apparently esoteric message "gt a gd jb & mo pa" which I was able instantly to interpret as "get a good job and more pay." The placard was advertising a new system of speed writing by means of which a speed of 120 words-per-minute could be obtained.

No doubt the system is new in the sense that this is the first time it has been offered to the public, but it is at least fifty years old to my certain knowledge, and more probably a century old.

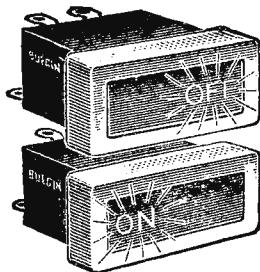
It is the unofficial abbreviated jargon used since the earliest W/T days by professional wireless operators when chatting with each other and of course by amateur transmitters too. Most of the early British and American wireless operators came from the ranks of Post Office and railway telegraphists, and they brought their jargon with them when they manned the early ship and shore wireless stations.

Long before the days of the "electric telegraph" we had the hilltop semaphore stations of Nelson's day and earlier. No doubt the operators of those semaphore stations used the same, or at any rate similar, jargon. By drawing attention to the similarity of the advertised speedwriting and unofficial telegraphese, I am not seeking to decry the former, on the contrary, I congratulate its sponsors in adopting and adapting such an excellent system.

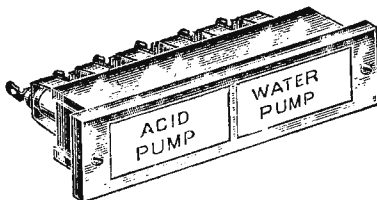
For the benefit of the curious, I would point out that the title of this note means "see you later, old man," and is, or at least was in my time, a very common piece of telegraphese.



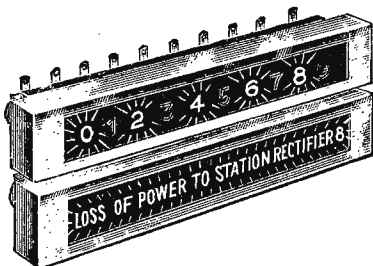
## LEGENDED SIGNAL LAMP FITTINGS



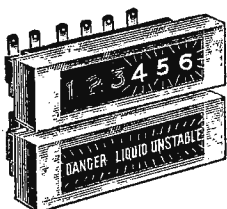
List No. D.720



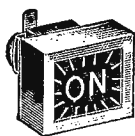
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# JANUARY MEETINGS

*Tickets are required for some meetings; readers are advised, therefore, to communicate with the secretary of the society concerned.*

## LONDON

2nd. Brit.I.R.E.—Symposium on “Masers and lasers” at 10.0 at London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1.

7th. Brit.I.R.E.—Symposium on “Radio and electronics research in Great Britain” at 2.0 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

10th. Radar & Electronics Assoc.—“Integrating electronics in missile and space systems” by D. C. Martin at 7.0 at the Royal Society of Arts, John Adam Street, W.C.2.

11th. Television Society.—“Modern receivers for the u.h.f. television service” by W. Bruch at 7.0 at Cinematograph Exhibitors’ Association, 164 Shaftesbury Avenue, W.C.2.

14th. I.E.E.—“Modern transducers with an electrical output” by Dr. J. Thomson at 5.30 at Savoy Place, W.C.2.

16th. Brit.I.R.E.—“Instruments in acoustics” by Prof. P. Bruel at 6.0 at London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1.

16th. I.E.E.—“Masers” by Dr. K. Hoselitz at 5.30 at Savoy Place, W.C.2.

17th. Television Society.—Fleming Memorial Lecture “Television signals—from transmitter to receiver” by Prof. D. J. E. Ingram at 7.0 at The Royal Institution, 21, Albemarle Street, W.1.

18th. Institute of Navigation.—“The navigation of satellites and their launching vehicles” by J. E. Clegg at 5.30 at the Royal Institution of Naval Architects, 10 Upper Belgrave Street, S.W.1.

18th. B.S.R.A.—“The line source loudspeaker and its applications” by P. H. Taylor at 7.15 at the Royal Society of Arts, John Adam Street, W.C.2.

21st. I.E.E.—“Magnetohydrodynamic waves in the ionosphere” by Dr. P. C. Clemmow at 5.30 at Savoy Place, W.C.2.

23rd. Brit.I.R.E.—Symposium on “Tunnel diodes as storage elements” at 6.0 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

24th. Television Society.—“Electronic aids to night vision” by Dr. P. Schagen at 7.0 at the Cinematograph Exhibitors’ Association, 164 Shaftesbury Avenue, W.C.2.

29th. I.E.E. and R.Ae.S.—Discussion on “Connectors in aircraft” at 6.0 at the Royal Aeronautical Society, 4 Hamilton Place, W.1.

30th. Brit.I.R.E.—“Propagation of television signals by satellite” by F. J. D. Taylor at 6.0 at London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

31st. I.E.E.—Discussion on “Resistance network analogues as aids to solving the laplace equation” opened by Dr. K. F. Sander at 5.30 at Savoy Place, W.C.2.

## ARBORFIELD

10th. I.E.E.—“Thinking machines” by D. J. Rowley at 5.0 at The Garrison Hall, Arborfield Camp.

## BIRMINGHAM

28th. I.E.E.—“The present state of colour television” by S. N. Watson at 6.0 at the James Watt Memorial Institute.

## BRISTOL

8th. Television Society.—“Measurements and servicing instruments” by P. J. Coe at 7.30 at Royal Hotel, College Green.

10th. I.E.E.—Faraday Lecture “Electronics—the key to air safety” by Dr. E. Eastwood at 6.0 at the Colston Hall.

23rd. Brit.I.R.E.—“Digital instruments and instrumentation” by Dr. I. R. Young at 7.0 at Bristol College of Science and Technology.

## CARDIFF

9th. Brit.I.R.E.—“Electronics in the steel industry” by D. J. Ray at 6.30 at the Welsh College of Advanced Technology.

30th. Society of Instrument Technology.—“The versatility of the electronic potentiometer” by F. W. J. Howard at 6.45 at the Physics Lecture Theatre, Welsh College of Advanced Technology, Cathays.

## CORK

24th. I.E.E.—“The Cork regional TV transmitter” by R. F. Law at 8.0 at the Victoria Hotel.

## DUBLIN

17th. I.E.E.—“Some basic engineering problems of operational TV” by E. J. Spain at 6.0 at the Physical Laboratory Extension, Trinity College.

## EDINBURGH

8th. I.E.E.—“Testing servo systems” by G. G. Gouriet at 7.0 at the Carlton Hotel, North Bridge.

9th. Brit.I.R.E.—“Switchable standard television receivers” by P. L. Mothersole at 7.0 at the Department of Natural Philosophy, The University, Drummond Street.

15th. I.E.E.—“Simulation of intelligence” by Prof. D. M. MacKay at 7.0 at the Carlton Hotel, North Bridge.

## FARNBOROUGH

10th. Brit.I.R.E.—“Television—past, present and future” by V. G. Hawkeswood at 7.0 at Farnborough Technical College.

## GLASGOW

7th. I.E.E.—“Testing servo systems” by G. G. Gouriet at 6.0 at the Royal College of Science and Technology.

10th. Brit.I.R.E.—“Switchable standard television receivers” by P. L. Mothersole at 7.0 at the Institution of Engineers and Shipbuilders, 39 Elmbank Crescent.

16th. I.E.E.—“Cybernetics” by Prof. J. C. West at 6.0 at the Institution of Engineers and Shipbuilders, 39 Elmbank Crescent, C.2.

## LEICESTER

14th. Television Society.—Lecture demonstration on the Decca Deram pickup by C. Clowes at 7.30 at the Collegiate Girls School, College Street.

## LIVERPOOL

7th. I.E.E.—“Data transmission” by R. H. Franklin and J. Rhodes at 6.30 at the Royal Institution, Colquitt Street

## MANCHESTER

9th. I.E.E.—“Xerography” by Dr. A. T. Starr at 6.15 at the Engineers’ Club.

## MIDDLESBROUGH

23rd. Society of Instrument Technology.—“Electronic versus pneumatic control” by C. H. Gregory at 7.0 at the Cleveland Scientific & Technical Institution, Corporation Road.

## NEWCASTLE-ON-TYNE

7th. I.E.E.—“Some improved methods for digital network analysis” by A. Brameller and J. K. Denmead at 6.30 at the Rutherford College of Technology, Northumberland Road.

## READING

16th. I.E.E.—“Satellite communications” by Capt. C. F. Booth at 2.15 at the J. J. Thompson Physics Laboratory, Reading University, Shinfield Road.

## SOUTHAMPTON

8th. I.E.E.—“Using a digital computer in transistor circuit design” by Dr. D. J. Truslove at 6.30 at The University.

29th. Brit.I.R.E.—“Some aspects of medical electronics” by D. H. Follett at 7.0 at the Lanchester Building, The University.

## SWANSEA

8th. I.E.E.—Faraday Lecture “Electronics—the key to air safety” by Dr. E. Eastwood at 6.30 at Brangwyn Hall, Swansea.

## WEYMOUTH

11th. I.E.E.—“Radio aids to air navigation” by T. Gray at 6.30 at South Dorset Technical College.

## FARADAY LECTURE

THE 1962/63 Faraday Lecture, the 34th in the annual series arranged by the I.E.E. to spotlight various aspects of electrical engineering in straightforward language for the layman, is entitled “Electronics—the Key to Air Safety.” It is being given in 12 cities and towns throughout the country by Dr. Eric Eastwood, director of research of Marconi’s W/T Company. The 1963 venues are:—Swansea (Jan. 8), Bristol (Jan. 10), Portsmouth (Feb. 12), London (Feb. 14), Manchester (Feb. 19), Leeds (Feb. 22), Newcastle (Mar. 25), Edinburgh (Mar. 28) and Dublin (Apr. 5) Admission is by free ticket.