The Journal of the

BRITISH INSTITUTION OF RADIO ENGINEERS

FOUNDED 1925 INCORPORATED BY ROYAL CHARTER 1961

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

VOLUME 23 JUNE 1962 NUMBER 6

RELIABILITY

CAN more be done to accelerate improvement in the standard of reliability attainable in complex electronic systems which have been and are being developed? There is reason to think so. Nor is this conviction restricted to the self-evident problems attending complexity. Frequently there is room for improvement in even the simplest devices intended for the most prosaic uses.

That this situation is not peculiar to electronics nor indeed to any particular fields of technological products is shown by the recent formation of the National Council for Quality and Reliability† sponsored by professional bodies representing all classes of engineering activities.

The association of the words "quality" and "reliability" requires no explanation but merits a full measure of reflection. For the present purpose it is expedient to ignore any rigid definitions of the words, whether framed in a technological context or not. The inference to be drawn from the association of the word "quality" with the objective of reliability is clear; the new body's role would be much less evident if its title did not bring the two words together.

Surely it is convenient to simplify the mental approach towards engineering reliability by accepting that the latter can be achieved only by an intelligent integration of two prime factors —quality of effort and reliable techniques.

It is essential to insist that by effort is meant the effort of everyone concerned. The technologist's obvious responsibility is for the incorporation of "reliable" techniques; he is inevitably implicated in applying these with the keenest regard for his own quality of effort. It is less obvious that he holds a responsibility for communicating a due measure of his own standard of quality to the operatives, craftsmen and technicians who support his work and to the administrative and management colleagues who influence it.

The vast complexity of military electronic systems has focused attention on unreliability and given rise to a mass of literature of a statistical and technical nature. Impressive facts bearing upon the heavy financial and operational penalties involved have been given wide publicity. Imperative as this is, unhappily it tends to overshadow the importance of the contribution made to unreliability by the essentially human failings to which administrative and procedural practices are very vulnerable. It is for this reason that the Institution's Technical Committee prefaced its recently-published bibliography on "Reliability of Electronic Equipment" with some precepts and observations of a general and non-technical character.‡

Complex technological systems demand comparably large personnel structures with an inertia correspondingly greater than that of small teams. This potential liability can and should be counterbalanced by individual contributions of the highest order of alertness and diligence to name but two of the numerous factors which comprise quality of effort.

The purpose of these remarks is not to remind technologists of the "quality of effort" factor in the reliability formula; to assume the need for such a step would be impertinent. Rather is it to point the way for them to exert an increasing measure of leadership in gaining from their associates in both the workshops and the administrative offices a greater appreciation of the contribution to reliability made by quality of effort.

F. G. D.

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† *J. Brit.I.R.E.*, **22**, page 362, November 1961.

‡ *J. Brit.I.R.E.*, **23**, pp. 287–95, April 1962.

INSTITUTION NOTICES

Birthday Honours List

The Council of the Institution has congratulated the following member whose name appeared in Her Majesty's Birthday Honours List:

Squadron Leader William Robert Francis Cooney, R.A.F., to be an Ordinary Officer of the Military Division of the Most Excellent Order of the British Empire.

Squadron Leader Cooney is at present attached to the Royal Radar Establishment, Malvern; from 1959 until March of this year he was officer commanding R.A.F. Communications Centre in Germany. He was elected an Associate Member in 1951.

Symposium on Sonar Systems

Members who wish to take part in the Symposium on Sonar Systems, which will be held in the University of Birmingham from 9th to 12th July, are reminded that the registration forms circulated in the May issue of the *Journal* should be returned without delay; this is particularly important if residential accommodation in the University Hall of Residence is required. The Symposium has attracted considerable interest and an attendance of scientists and engineers from all over the world is expected. The programme of the Symposium is printed on page 501 of this *Journal.*

Completion of Volume 23

This issue completes Volume 23 of the *Journal* which covers the period January–June 1962. An index to the volume will be circulated with the August issue.

Members are reminded that they may have their half yearly volumes (six issues) bound at 16s. 6d. per volume (postage extra: 3s. Great Britain; 4s. Overseas). The issues and the appropriate indexes should be sent to the Publications Department, at 9 Bedford Square, London, W.C.1, with remittance.

Change of Address—an Urgent Request

All members are earnestly requested not to delay in advising the Institution at 9 Bedford Square, London, W.C.1, immediately they change their address.

It is *not* necessary for members to notify local section secretaries in Great Britain of their change of address. Such notifications are automatically sent from Head Office to the local sections. Because of delays in post, however, overseas members should advise their Local Secretary *at the same time* as they advise London.

Failure to notify the Secretary at 9 Bedford Square causes considerable delay in members receiving *Journals*, notices of meetings and other separate communications. In addition there are extra postal charges involved due to letters being returned to the Institution.

Canadian Proceedings of the Brit.I.R.E.

Members will recall that the first issue of the new Institution publication bearing the above title appeared last autumn. It is the intention of the Council that subsequent numbers should be largely produced by members in Canada and printed locally. To this end Mr. Geza Zelinger (Member) has been appointed Honorary Editor and he will be assisted by a small editorial panel (Messrs. M. W. S. Barlow, M.A. (Associate Member), K. N. Coppack (Associate) and D. F. Gilvary (Graduate).) Contributions of papers, short research and development notes, and news items for the *Canadian Proceedings* are cordially invited, particularly from members within Canada and the United States. Offers of such material should be sent to Mr. Geza Zelinger, 4655 Bouchette Street, Montreal 26.

Group Provident Scheme

The British United Provident Association (B.U.P.A.) is a service which operates in the United Kingdom for subscribers who wish to cover themselves for private hospital treatment instead of treatment under the National Health Service. The Institution has established a Group Scheme for members with the co-operation of the B.U.P.A. and details of annual subscription rates, medical benefit, etc., may be obtained from the Group Secretary, B.U.P.A., 9 Bedford Square, London, W.C.1. Participation in the Scheme is also open to members of European nationality who are resident in Commonwealth countries and those interested should also write to the Group Secretary.

Whitworth Awards for Engineers

Engineers are invited to apply for one of the three Whitworth Fellowships for 1963 now being offered by the Ministry of Education. The awards are worth £1,000 a year plus additions for dependants, travelling and subsistence where appropriate. They enable engineers to follow approved courses of training, study or research at the postgraduate level in this country or overseas. Three Whitworth Exhibitions of £100 will be awarded to unsuccessful candidates whose work deserves recognition.

Men and women are equally eligible but must be over 25 and have at least three years experience as practising engineers after obtaining a university degree in engineering, a Dip. Tech. (Eng.) or H.N.D. or H.N.C. in engineering with at least two distinctions or some other qualification approved by the Minister of Education as of equivalent standard. Further details and application forms can be had from the Ministry of Education (FE1Gen.), Curzon Street, London, W.1. Closing date is 31st July.

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Detection of Nuclear Explosions in Space and Underground

By

I. MADDOCK, O.B.E., B.Sc.
(*Member*)†

Based on a lecture to Section A of the British Association for the Advancement of Science at the Annual Meeting in Norwich on 1st September 1961.

Summary: Nuclear explosions in space may be detected by the emission of electromagnetic and particle radiation. Detection instruments may be carried in satellites. The capabilities of the various techniques are reviewed. Seismic methods for the detection of underground explosions are discussed. Signal/noise ratio problems predominate and a seismometer array is described which provides discrimination against waves from different sources.

1. Introduction

It is not necessary to explain the significance of the negotiations which have taken place at Geneva on the discontinuance of nuclear weapon testing. This paper will not refer in any way to the political issues which are involved; it is confined to a discussion of the scientific and technical problems and the studies which are proceeding in the U.K. Atomic Energy Authority. It is sufficient to note that the technical objectives were to produce a system which would be able to detect nuclear explosions of one kiloton (1000 tons of TNT equivalent) fired within the atmosphere, or underground, or in that region of space which will be accessible by rocket devices available in the foreseeable future.

The detection of explosions within the atmosphere (and we can include here those which are fired at a shallow depth in the sea) is quite well understood and there are no problems in this sector which cannot be resolved by a moderate amount of development. The difficult regions are space and underground, for somewhat different reasons. In space we have the difficulty that the only evidence of a nuclear explosion will be a very limited amount of instrumental data. It will not be possible to do an "on site inspection" or even positively to identify the culprit—the instrument must stand alone, and therefore must be highly reliable and free from ambiguity. On the other hand, a nuclear explosion in space gives rise to a number of different detectable effects and the simultaneous recording of two or more of these would add to the reliability of the system.

In the case of underground explosions the position is different. On the credit side we have the fact that the radioactive debris is permanently trapped and is therefore open to discovery and subsequent study, but heavily on the debit side is the fact that the only detection method which can be used at long distance is the observation of the seismic signal. It is an unfortunate fact that the signals received at a distance are governed in the main by the nature of the transmission path rather than the source itself, and this causes signatures from explosions and those from earthquakes to be very similar.

This paper gives a brief review of the detection problems which obtain in space and underground and the detection methods which are being studied.

2. Explosions in Space

It is convenient to start by describing the various effects which arise when a nuclear explosion is fired in space. Figure 1 shows in diagrammatic form the parameters which could be used for detection purposes, and it is related to a nuclear yield of one kiloton at a range, R. The prompt neutron and gamma outputs shown are produced during the nuclear explosion itself. They are generated in an extremely short time (about 10^{-8} to 10^{-7} second) and because the gamma radiation travels at the speed of light, c, a compact bundle of gamma photons will arrive at a distance R, which has the same short duration as the original explosion. During this time interval the flux is extremely high and one sensitive method of detection is, therefore, to look for a very short duration burst of gamma radiation. This calls for instruments which have a very high time resolution and which also can discriminate against the random short bursts caused by the background "noise".‡

The neutrons travel at speeds which lie between $\frac{1}{10}$ and $\frac{1}{2}$ the velocity of light and they therefore become

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† Head of Field Experiments, Atomic Weapons Research Establishment, Aldermaston, Berkshire.

‡ Noise in this context is considered to be any form of interfering signal, whether it originates from thermal type sources or from random events.

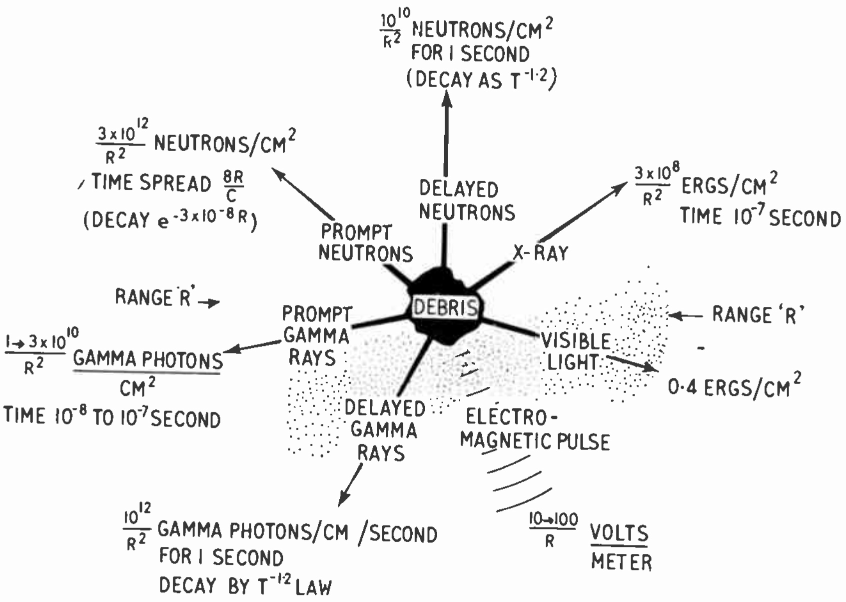

Fig. 1.
The detectable effects of a 1 kiloton nuclear explosion in vacuum.

spread out along the flight path. This gives a time spread of $8R/c$. In addition, the lifetime of neutrons is limited (approximately 1000 seconds) and after travelling some distance they dissociate into electrons and protons. The neutron beam is depleted and this leads to the decay factor $\exp(-3\times10^{-8}\times R)$.

After the explosion, there will be a mass of debris, which will expand rapidly. This debris will contain the fission products which will be producing gamma radiation and neutrons by radioactive decay processes. These are shown in the diagram as "delayed gamma rays" and "delayed neutrons". As the decay process proceeds, the source gradually gets weaker and the flux reduces at the rate $N = N_0T^{-1\cdot2}$. This is a slow process and under certain circumstances the delayed gamma rays and neutrons may be detectable for many days.

Only a relatively small fraction of the energy of a nuclear explosion appears in the form of nuclear radiations or sub-atomic particles (less than 10%). The major portion (probably between 50% and 70%) appears in the form of heat, but so high is the temperature of the source, the "heat-rays" appear as a very soft x-ray. The wavelength of these x-rays is greatly dependent on the mass to energy yield ratio of the nuclear device which has been exploded. A large yield coupled with low total mass—which includes all of the mass in the payload—will give a high temperature, whereas a low yield in a massive assembly will produce a much lower temperature. Typically, a nuclear explosion in space can be regarded as approximating to a black-body radiator at a temperature of one kilo-electron volt.

Not only is there a large proportion of the energy in x-radiation, it is also released in a very short time interval—about one tenth of a microsecond. Thus the instantaneous flux is extremely high and this gives rise to the most effective method of detecting explosions in space. It is worth noting that when a nuclear explosion occurs in the atmosphere, the x-ray energy is rapidly absorbed by the air in the immediate neighbourhood, causing it to heat up to a very high temperature. It is the very rapid expansion of this heated air that gives rise to high blast pressure, and it is this which causes most of the non-radioactive damage normally associated with a nuclear weapon.

There are three further effects produced by a nuclear explosion in vacuum which can be used for detection. First, there is an intense flash of light in the visible or near visible region of the spectrum, which is a natural consequence of the hot-body radiator already described. The second is the result of a more complex mechanism. When the intense prompt gamma burst occurs, many of the gamma photons collide with the electrons which exist in the materials of the device itself and the surrounding structure. This gives rise to a Compton electron avalanche moving out radially in all directions. After a short interval, the situation becomes complicated by the fact that the device materials will have become sufficiently positively charged to prevent the escape of further electrons and also to attract back some of the slower ones which have already been ejected. A complex state of equilibrium is established between electrons which escape completely, those which are attracted back, and those which can still manage to leave the device materials. The combined effect of this mechanism and any asymmetry in the mass distribution in the device will give rise to an electromagnetic signal; its precise waveform and amplitude are not known,

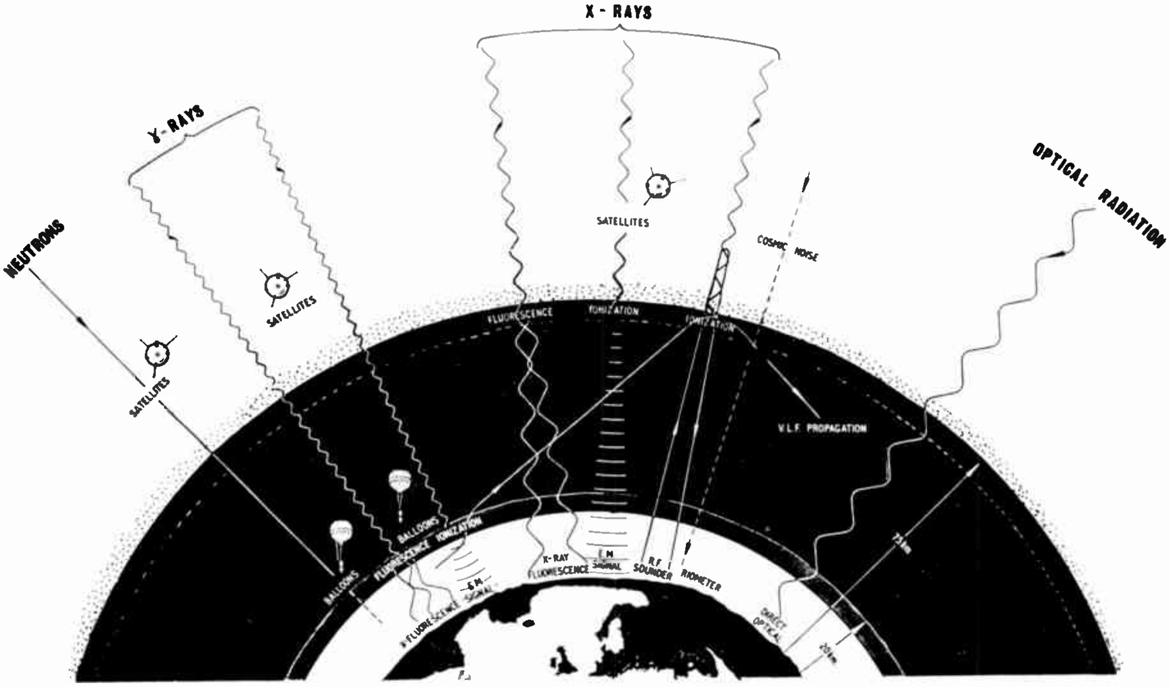

Fig. 3. Proposed systems for detecting weapon tests in outer space.

but it is believed that it will have a characteristic frequency in the region of hundreds of megacycles.

The remaining effect of interest in the detection problem arises as a consequence of the radioactive decay of the fission products in the debris. The radioactive debris produces beta particles (i.e. electrons) which are trapped in the Earth's magnetic field by the same process that leads to the Van Allen radiation belts. These electrons spiral along the Earth's magnetic lines of force as shown in Fig. 2. These lines of force converge as they approach the Earth and this causes the electrons to be reflected back along the lines of force. In this way the spiralling electrons can "bounce" between the two ends of the magnetic lines of force for some time, until they are captured by collision with atoms in the upper atmosphere.

Where the electrons come closest to the Earth, they will penetrate into the upper atmosphere and can produce effects analogous to aurora. These take the form of visual effects—an air-glow—and ionization effects which can be observed by radio methods. It is of particular interest that a nuclear explosion at a great height in the southern hemisphere (say in the South Atlantic or Pacific) could be observed by the auroral effects produced in the northern hemisphere. Unfortunately, such observations are very difficult in the natural auroral regions and they will also be restricted by cloud cover, electric storms etc.

The fact that the electrons remain trapped for a long time (from hours to days) makes it possible to detect them by means of relatively simple instruments in satellites in orbits near the Earth.

3. Detection Methods for Space Explosions

The various methods which can be used for detecting nuclear explosions in space are illustrated in Fig. 3. It will be seen that very few of the effects described earlier can be observed directly on the surface of the earth. The neutrons and gamma rays are stopped at a height of 20–25 km by absorption in the atmosphere, whilst the x-rays are stopped at even greater heights (75–100 km). The only effects which can be observed directly are the thermal radiations in the visible region of the spectrum (referred to as optical radiation in the diagram) and possibly the electromagnetic effect.

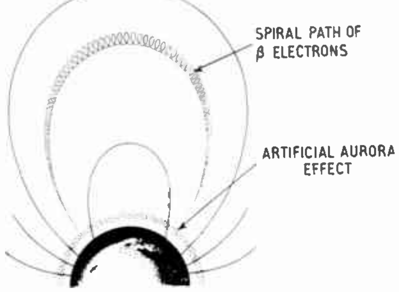

Fig. 2. Argus effect—the paths of electrons along the Earth's magnetic lines of force.

3.1. *Gamma Rays and X-Rays*

Fortunately, however, it is possible to record the explosion effects indirectly, by observing their interaction with the atmosphere. Both the gamma radiation and the x-rays cause the air to become ionized and this produces a sudden change in the character of the ionosphere and also a luminous effect analogous to the aurora. An important point, however, is that these phenomena will have a very rapid onset and in the case of the atmospheric luminosity will be of very short duration.

The following indirect methods of detection are possible:

(*a*) *X-rays by luminosity effects*

Both theory and experiment have shown that the x-ray deposition in the atmosphere at a height of 75–100 km produces a short flash of light, with a high intensity in the near-ultra-violet line of wavelength 3914 Å. A system of photocells looking at various sectors of the sky with narrow band filters and arranged to respond only to sharp changes of intensity will detect nuclear explosions in space. Wilson of the U.K.A.E.A. has pointed to the fact that there should be a corresponding high intensity in the infra-red region of the spectrum at a wavelength of 8911 Å. This has the merit that infra-red radiation penetrates the atmosphere more readily than ultra-violet, and more efficient narrow-band filters and radiation detectors can be made. The limit to these methods is set by the statistical variation in the background light (i.e. they are much more effective at night time), disturbance due to lightning and the input noise of the photo-sensitive element.

(*b*) *X-ray ionization effects*

The mechanisms at work which produce ionization from the x-ray from a nuclear weapon are identical to those which normally lead to the creation of the ionosphere. Thus it is possible to make use of the radio methods which have been used to study the ionosphere as a means of detecting nuclear explosions. The main point of difference between the nuclear explosion and solar-induced effects is that the explosion produces a very sharp onset of ionization, which can be exploited to increase the sensitivity of the radio methods. The methods which can be used are:

1. Vertical incidence sounder

This technique has been used extensively over many years to study the ionosphere. Pulses of radio waves are beamed vertically upwards and the time taken for the reflected waves to reach the ground is recorded by the A-scan technique used in radar. As the frequency is swept through the range 5 to 40 Mc/s, "echoes" are received from the D, E and F layer systems and a height versus ionization density plot is obtained.

The system has to be modified to suit the purposes of nuclear explosion detection. In this case there will be a sudden onset of ionization at a given height and the radio sounding method must have sufficient time resolution to observe the rapid change. The choice of radio frequency must be such that very small and rapid changes of electron density in the 75 km to 100 km region will be located and this will have to be adjusted to suit the existing ionospheric conditions.

2. Absorption of cosmic noise from space

The cosmos provides a continuous source of radio waves from outside the atmosphere and these can be used to study the state of the ionosphere. For detection work, a band of frequencies would be used which is very close to the cut-off frequency, due to the ionosphere, existing at any given time. A sudden onset of additional ionization will produce a sharp fall in the cosmic radio noise level.

Unfortunately the sun can produce effects which are somewhat similar—the so-called "sudden ionospheric disturbance" (s.i.d.) produced by hot-spot explosions on the solar surface. In general these are much slower in their development than the effects of nuclear explosions, but it is possible that short sharp disturbances can also exist.

3. Very low frequency phase shift

The radio waves from a very low frequency (v.l.f.) transmitter will reach a receiver by two routes—the "ground wave" and the "sky wave" which has experienced one or more reflection at the ionosphere. There is therefore a phase shift between the two arrivals and this is a parameter which can easily be measured. Any change in the apparent height of the ionosphere produces a corresponding change in phase, and a nuclear explosion would produce a shift which would be much more rapid than that normally experienced from solar induced effects.

The sensitivity of each of the methods is governed largely by the variability of the ionosphere due to solar influences, and by interference from man-made sources.

3.2. *Neutrons*

The neutrons penetrate to the height where it becomes practicable to detect them by instrumentation in very high altitude balloons. This method can only be used on a sampling basis, but is relatively cheap and can be done at many points on the surface of the Earth.

3.3. *Electromagnetic Effect*

In addition to the electromagnetic effect described earlier, associated with the Compton electrons from the device itself, there is another mechanism which will produce a detectable signal. Both the gamma and x-radiation will produce a Compton electron burst when incident on the upper atmosphere, and this leads to a vertical current vector. This produces an electromagnetic signal which is similar in many respects to the interference signals produced by lightning. Such signals can be registered by instruments which are a variation on those normally used for electric storm detection. It is worth noting here that electromagnetic signals of an analogous kind are produced when nuclear explosions occur within the atmosphere, and these can be detected over great distances.

3.4. *Optical Radiation*

Thermal radiation in the visible region of the spectrum can penetrate the atmosphere, and the short duration flash from an explosion presents another method of detection. It is limited by the natural sky brightness and is therefore much more effective at night. It is also limited by the background due to electric storms and man-made disturbances.

3.5. *Detection by Satellites*

Since most of the explosion effects are not observable from the surface of the Earth, there are obvious advantages in mounting the detection instrumentation in satellites. Basically such satellites need only be at sufficient height to be clear of the atmosphere, but there are advantages in placing them in much wider orbits. A particular problem arises from the existence of the Van Allen radiation belt. Figure 4 shows the distribution of particle densities as published by Professor Van Allen, where it will be seen that between the heights of 700 km and 25 000 km there is a high background of radiation. Whilst schemes have been proposed that would enable detectors to work within this radiation environment, the equipment would be simpler and more reliable outside these zones. This tends to split the satellite systems into two groups, the near earth (below 700 km) and the far earth (beyond 25 000 km).

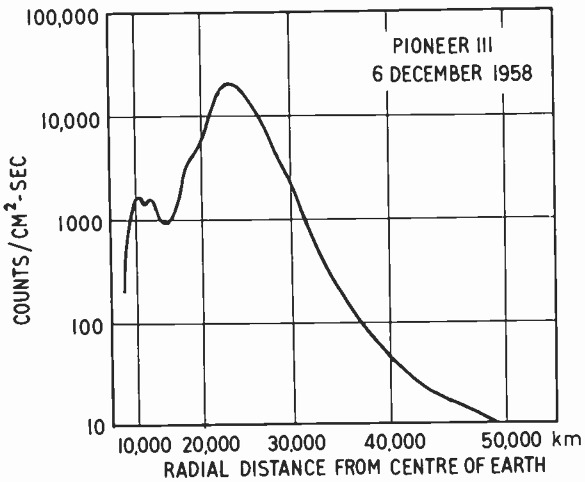

Fig. 4. Distribution of particle densities in space.

The methods which can be used to good effect in a satellite are:

prompt gamma radiation
delayed gamma radiation
prompt neutrons
delayed neutrons
thermal x-rays

The prompt gamma ray method exploits the short duration and very high flux of the burst which, by using coincidence methods, can be distinguished from the background. Delayed gammas have the advantage that they persist for a long time and, since they originate from the debris, they are difficult to conceal. Prompt neutrons are of no great value since the pulse of neutrons is a relatively long one due to the low and widely dispersed velocities. Delayed neutrons are of more potential value, but all neutron methods are limited by their finite lifetime. Thermal x-rays are of considerable value for detection purposes, because of the high flux which exists for a very short time. They can, however, be shielded by a very thin screen, and in order to make such shielding difficult it is necessary to detect very "soft" x-rays. This calls for some very refined techniques which will not be described here.

It is envisaged, therefore, that a satellite will be equipped with apparatus for detecting "soft" x-rays, delayed gamma radiation, prompt gamma radiation and neutrons; it must also have equipment which determines the ambient background and have safeguards against interference from solar radiation, cosmic particles, solar winds and micro-meteorites. This gives rise to complex design problems, but many of these have been encountered and solved in the satellites already launched. Above all, it must have a very high inherent reliability and be equipped with internal monitoring equipment which will declare when faulty functioning occurs.

3.6. *A Typical Detection Satellite*

The simplest way to detect the x-rays is by using a very thin scintillator viewed by a photomultiplier. This, however, will also respond to low energy charged particles, but these can be minimized by using a thin shield of a material with high atomic mass. A further problem arises from high energy particles

Table 1.

Noise Sources

Method	Interfering signals	Comments
X-rays by atmospheric fluorescence.	Statistical noise in photosensitive element.	Varies with sky brightness and spectral region used. Effect reduced by increasing detector area.
	Variations in sky brightness due to atmospheric effects (clouds etc.).	Slow, probably not significant.
	Lightning.	Localized effect, large in some spectral regions, small in others. Eliminated by coincidence with other stations in network.
	Solar flare, aurora, and other atmospheric luminous effects.	Mean level low but nature not known; probably slow pulses and not significant.
	Meteorites.	
	Natural x-ray background.	
Prompt and delayed γ-ray measured from balloons.	Photo-electron statistics in detector.	Photon flux low compared with x-rays.
	γ bursts arising from cosmic rays and particles.	
	Natural γ background.	Large component due to atmospheric back-scattering—might be eliminated with directional detectors.
X-rays by ionization effects—v.i.f., ionospheric sounding, or cosmic noise absorption.	Normal ionospheric activity.	Slow time constant of ionosphere accumulates effects of disturbance over long period (minutes).
	Solar induced sudden ionospheric disturbances.	
	Lightning storms.	Long range effect difficult to distinguish from weapon.
Direct optical.	Photo-electron statistics.	Intensity several orders lower than x-rays.
	Atmospheric variations. Lightning. Man-made flashes. Luminescent effects.	Weapon gives point source of light difficult to isolate and susceptible to cloud obscuration, but if isolated most interference is eliminated.
Satellite-borne γ-ray detectors.	Photo-electron statistics.	Photon flux low compared with x-rays.
	Cosmic ray avalanches.	Background low, but rare events cover wide area.

Table 1 (*Contd.*)

Method	Interfering signals	Comments
Satellite-borne neutron detectors.		Range limited by natural decay of neutrons and time-spread.
	Neutron albedo of earth.	Back-scattered neutrons eliminated by directional detectors.
	High energy protons in Van Allen belt.	
	Micro-meteorites.	
Satellite-borne x-ray detectors.	Photo-electron statistics.	Background low due to absence of scattered solar light.
	Sun's corona. Solar winds.	Volume of detector small compared with fluorescence, but solar effects can be eliminated by directional detector.
	Cosmic charged particles.	
	Lyman—alpha from sun.	Wavelength long; can be filtered off except when detecting heavily shielded weapons.
Balloon-borne neutron detectors.		Range limited by natural decay of neutrons and time-of-flight spread.
	Cosmic rays. High-energy protons.	Interactions rare above balloon height from solar winds.
	Neutron albedo of earth.	Worse than for satellite-borne but directional detectors eliminate most.

amount of ingenuity and determination and technical resources one is prepared to ascribe to such a project. With the current rate of development of satellite launching skill, it must be expected that great ranges and large payloads will become common. Nuclear tests at great ranges must therefore be regarded as feasible.

A reliable detection system, which will detect any nuclear explosion of one kiloton or more out to distances of 100 000 kilometres, is practicable, and up to distances approaching ten million kilometres for explosions in the megaton range. Coverage of greater distances must rely on one detection method alone—the x-ray—and must be exposed to the doubts that this implies.

4. Underground Explosions

Turning now to underground nuclear explosions, a very different situation obtains. In this case only one method of detection is available—by means of the seismic signals produced—but there is the compensation that the radioactive debris will be permanently trapped and is therefore available for subsequent inspection. This leads to the concept of "on site inspection", which is an essential component in a detection system for underground nuclear explosions. It is important, however, to emphasize that there may be difficulties in locating a body of nuclear debris underground, even when there has been an accurate determination of the probable epicentre of an explosion.

Figure 6 serves to indicate the complexity of the seismic waves which arrive at a detection station. For any source, be it earthquake or explosion, the following sequence of seismic waves is produced:

(1) P waves. These are longitudinal body waves leading to particle motion towards and away from the source. They have a propagation velocity of about 6 to 8 km/s, depending on the medium.

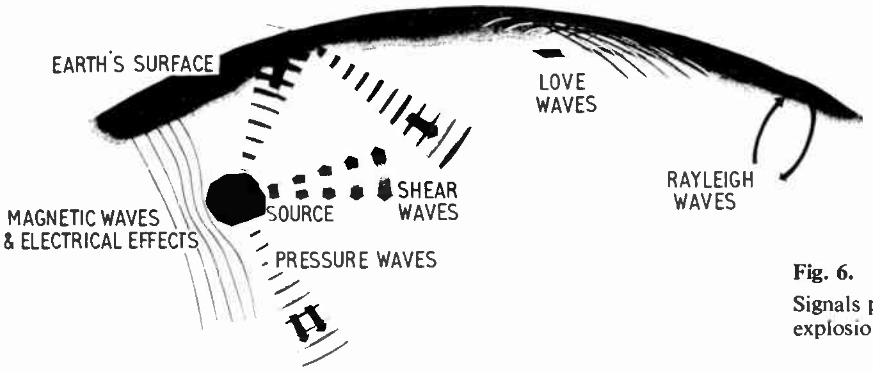

Fig. 6.
Signals produced by underground explosion and earthquakes.

(2) S waves. These are transverse body waves, producing tangential particle motions, which may be orientated in any direction. They travel at six-tenths of the velocity of P waves.

(3) Love waves. These are horizontal transverse waves, which travel along the earth's surface at a velocity of 4 to 4½ km/s.

(4) Rayleigh waves. These are vertical waves which cause a particle to execute an elliptical motion with its plane lying along the axis of propagation.

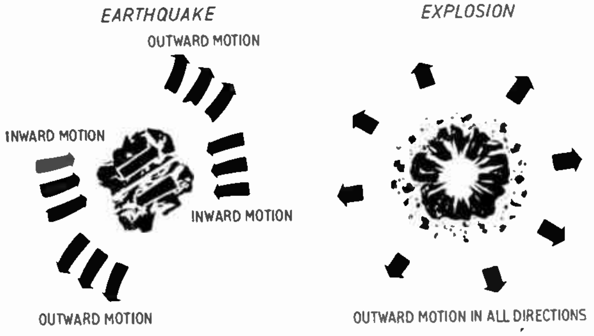

Fig. 7. Direction of first motion for earthquake and underground explosion.

In addition, the P and S waves are subject to reflections and refractions, whilst the surface waves suffer dispersion, and all this leads to different arrival times of all the various wave trains. The result is a complex series of oscillations whose nature is governed almost entirely by the characteristics of the transmission paths and hardly at all by the source itself. This makes it difficult to distinguish between earthquakes and explosions and it is one of the primary aims of the U.K.A.E.A. research programme to find some methods of discrimination. Since the only part of the wave train which arrives undisturbed by later modes is the first arrival (i.e. the P wave), it is natural to seek an indentification criterion in this. Figure 7 shows the principle which is used. In an earthquake, a large shear motion occurs, due to excessive stresses which have been built up along the fault planes. This leads to two great masses of rock moving suddenly in opposite directions and the result is a pattern of inward and outward motions as shown. It is possible, therefore, to divide the region around an earthquake into four sectors, and in two non-adjacent sectors there will be a compressional first motion, and in the other two a rarefaction.

In the case of an explosion, however, the situation is different. The motion is outwards in all cases, and the direction of first motion in the seismic wave is compressional in all directions. Thus if the direction of first motion can be determined in a sufficient number of stations at various azimuths relative to a source, it should be possible to determine its nature. Unfortunately, an important feature of the Earth's

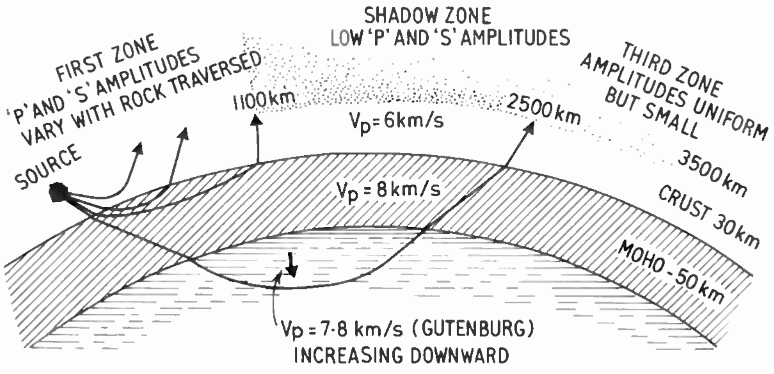

Fig. 8.
Body wave propagation paths.

structure makes this difficult and this is demonstrated in Fig. 8. There is a sharp change of velocity of body waves at a depth which varies over the surface of the Earth, but is in the region of 25 km. This is known as the Mohorovicic discontinuity, and hereafter referred to as the Moho. The body waves travel downwards and outwards in the relatively slow crustal medium until they reach the Moho. They then travel outwards more rapidly, and as they do so they radiate *upwards* towards the surface. The result is that the first body waves to arrive at a station are usually those which have traversed along the Moho, followed by the P wave which has travelled by a curved route through the crust. At a certain incident angle to the Moho an effect analogous to the critical angle in optics occurs, and the wave penetrates into the high velocity medium and follows a curved path through the Earth's mantle. The result is that the waves "skip" an annular region around the source stretching from 1000 km to 2500 km approx. and this leads to what is known as the "shadow zone". Thus a detection station, to be effective, must be in the area before the "shadow zone" (called the first zone) or right beyond it (called the third zone). Unfortunately, the signals become much weaker in travelling out to the third zone and a source has to be very "powerful" to produce clear and unambiguous first motion signatures at this distance.

The network of detection stations recommended by the Geneva Conference of Experts in 1958 is based on a standard spacing of 1700 km between stations, which is reduced to 1000 km in regions of high seismic activity. This produces a situation where there are rarely more than two stations in the first zone and this makes it difficult to implement the first motion criteria. If the third zone stations could be made to yield good clear records of the first motion, the situation would be improved, and this is one of the reasons for the research now proceeding into methods for improving the signal-to-noise ratio.

It is important to realize that noise in the context of seismology is quite different to what is meant by the word in communications. In the latter it is regarded as a purely random source which can be described by a temperature or by a resistive value. In seismology the noise is just another signal which may originate in the immediate neighbourhood of the station due to such *random* influences as the wind in the trees, thermal stresses in buildings, industrial and domestic noises etc., or it may arise from remote sources. The former may be similar in character to communications noise and can be minimized by careful choice and arrangement of site, but the latter will appear as a definite interfering source. The most prominent cause of such interfering signals are the microseisms which are originated by storm or major wave patterns in the ocean. These signals have certain characteristics and are frequently coherent (i.e. not random) in character. Figure 9 is a graph due to Oliver showing the distribution of energy with period in microseisms and it can be seen that they produce a powerful source of interference in the region between one and ten seconds period. This has led to the tendency to split seismic instrumentation into two classes, "short period" (1/100 to 1 second) and "long period" (10–100 seconds) in order to avoid the microseismic sector of the spectrum.

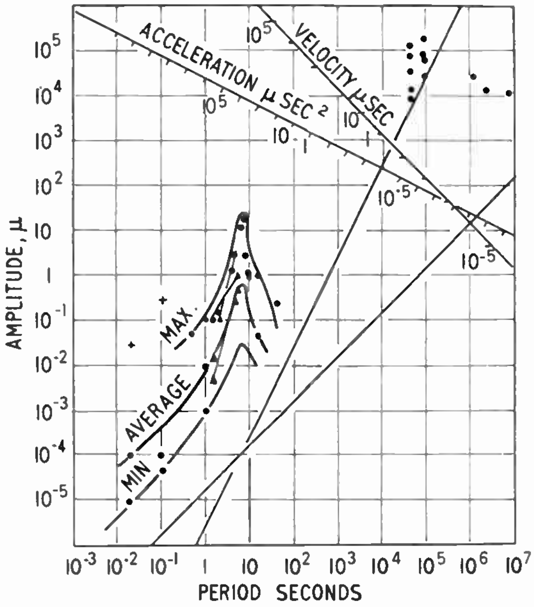

Fig. 9. The seismic noise of the Earth's surface.

In order to appreciate fully the signal-to-noise ratio problem it is necessary to consider the shape of the first arrival waveform. A typical wave shape is shown in Fig. 10 and it will be noted that the amplitude of successive half waves is increasing. There is some evidence that in the case of underground explosions the relative amplitude of first to second peak changes from 1 to 3 at a distance of 350 km to as much as 1 to 10 at 1000 km, although it is possible that the change is not as great as this. If there is noise present which compares in amplitude with the first peak, it

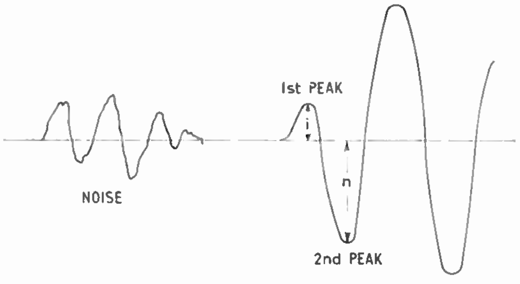

Fig. 10. First arrival "P" waveform.

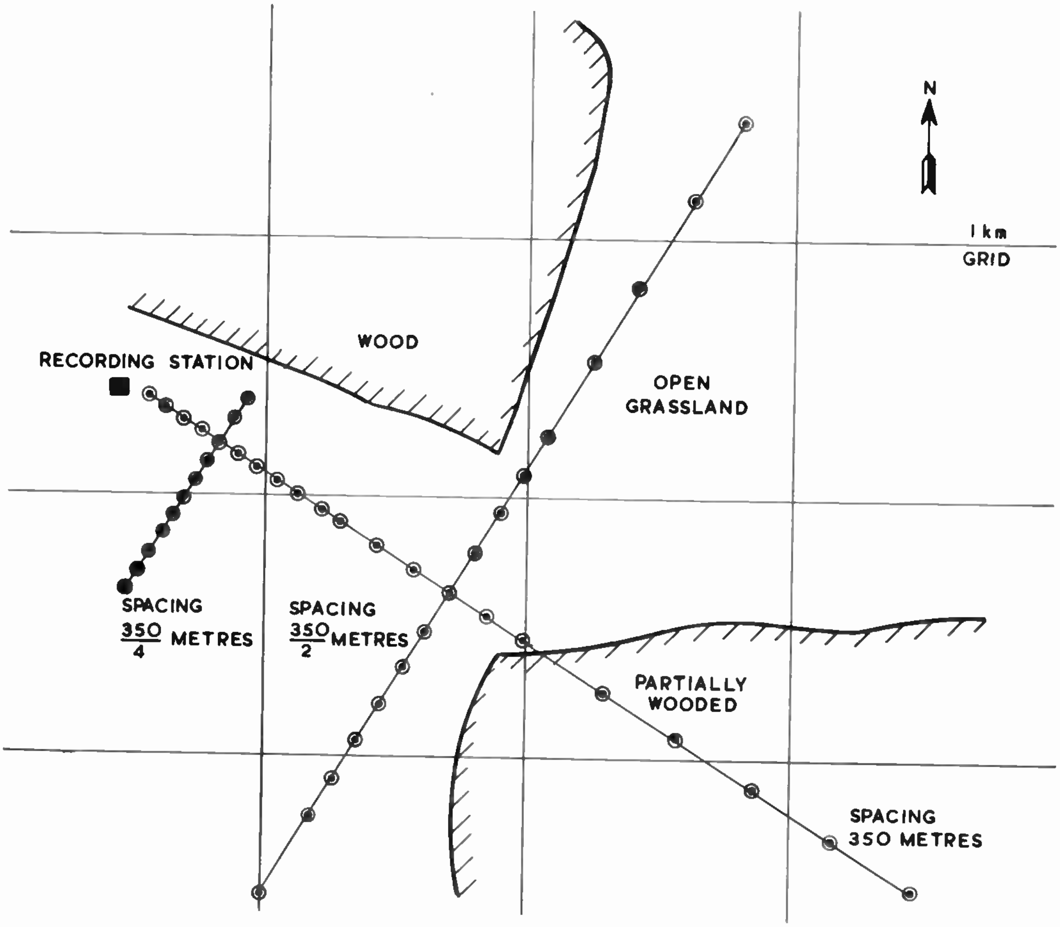

Fig. 11. Seismometer array on Salisbury Plain.

is possible to identify incorrectly the second peak as the "first motion". This effect can completely change the conclusions about the nature of a source and is of very considerable importance to the detection problem.

4.1. *Improving Signal-to-Noise Ratio*

It is not possible to give any more than a brief reference to the methods which are under development to improve the signal-to-noise ratio. The first step is to improve the seismic instruments themselves by:

(a) Increasing sensitivity, since the detection system is primarily concerned with weak signals.

(b) Increasing the bandwidth, because the important characteristics are likely to be concealed in detailed structure, and also because the power spectrum varies with distance. The principle has been adopted by the U.K.A.E.A. of using the maximum practicable bandwidth when recording and then restricting the bandwidth subsequently to suit the parameter being studied.

(c) Improving the methods of registration, and particularly to arrange for records to be made in a way which can be played back for later data analysis.

The next step is to improve the powers of discriminating one signature from another. A certain amount of this can be done by conventional filtering techniques, but to achieve a significant improvement it is necessary to include the Earth itself into the station system by exploiting two important facts:

(1) The various waves travel at different speeds and can therefore be identified in character and direction.

(2) Most local noise is in the form of surface waves which attenuate sharply with increasing depth.

One method of improving signal-to-noise ratio and also the power of discrimination is to use a seismometer array. Figure 11 shows an array which has been used by Whiteway of the U.K.A.E.A., consisting of seismometers arranged in the form of a large cross. A seismic signal from a given source will sweep across the array at a known speed and will produce an identical signature at each seismometer. The various seismic modes will traverse the array at different speeds, whilst interfering signals from other sources (e.g. microseisms) will also sweep across the array from different directions and with different speeds. Thus, by summing up the outputs from each seismometer with a progressive time displacement across the array (called tuning the array) the signal can be accumulated in preference to the noise. By varying the time shift the various seismic modes can be selected and this is a powerful method for recognizing the onset times of each mode. In certain cases, the array can be tuned to highlight a significant coherent noise (i.e. interfering source) and then this characteristic may be subtracted from the original signatures. Further, by using cross-correlation between the line arrays it is possible to point to the exact time of onset of a new train of waves, which greatly assists in application of certain criteria.

Another method of improving signal-to-noise ratio is to make use of a deep borehole. This makes use of the fact that at the surface a seismometer will record signal plus noise, whereas at some depth a seismometer will record the same signal (which is travelling upwards through the earth) and a reduced and somewhat modified form of the noise. Thus by "correcting" the waveforms from the lower seismometer to the surface equivalent and subtracting this from the upper signatures, the signal can be separated from noise.

It will be noted in all of these techniques it is necessary to process the data after recording. This means that the recording method used must permit direct electrical playback in some way—an approach which is a break-away from the traditions of seismology.

The U.K.A.E.A. is making a detailed study of instrumental developments, array systems, the use of boreholes and advanced analysis methods.

4.2. *Other Criteria*

Other criteria exist which help in the discrimination of earthquakes from explosions. They are:

(1) *Epicentral location.* By observing the arrival times of the wave trains at a number of stations, and with some knowledge of the wave velocities, it is possible to deduce the area from which the signal originated. The accuracy to which this can be done is governed partly by the ability to identify to the exact moment of arrival (it is easy to miss some half periods of the signal) and the reliability of the knowledge of wave velocities. Typically, an area of 200 km square is quoted, but this may be very much worse where data from only a few stations are available, particularly if these are all to one side (e.g. in a coastal region). If the location proves to be in areas where nuclear explosions are improbable, e.g. deep sea, populated areas etc., the event can confidently be ascribed to an earthquake. If, on the other hand, an event is recorded in an area which is known to have very little seismic activity, it must be classified as a probable explosion.

(2) *Depth of Focus.* Most earthquakes occur at great depths, whereas it is very improbable that a nuclear explosion would be fired at a greater depth than one or two kilometres. Thus if accurate depth determination can be made this will make it possible for a large percentage of events to be identified as earthquakes. The standard method for doing this is by observing arrival times and using known travel times by the same technique as is used in epicentral location. This, however, is subject to the same errors and it is difficult to discriminate between the depth of events in the upper 20 km of the Earth's crust. Thirlaway of the U.K.A.E.A. has shown that an old method based on the different arrival time of the two main P waves and the first S wave can be made to give good depth determination when used with modern instrumentation. This method, is, however, only effective in the first zone, and in areas where the geology is not complicated by complex folds and faults.

4.3. *Capabilities*

The capability of any given system to detect underground nuclear explosions is a subject of too much complexity to be discussed in a survey paper of this kind. It is sufficient to state that there are many thousands of earthquakes per year which produce seismic signals of amplitude comparable to those from a one kiloton explosion, and therefore a very high percentage of these will have to be positively identified as being of natural origin if the number of "suspect" events is to be kept within bounds.

Thus, whereas the original aim of the detection studies was to find methods of recording nuclear explosions, it has now become a challenge to find methods of positively identifying small earthquakes as being such.

5. Conclusion

It is not possible in a brief review of this nature to cover the extensive area of science which is involved nor to discuss the capabilities and limitations in any detail. It is hoped that this communication will serve to give some idea of the scope and complexity of the subject and show where some of the pitfalls lie.

Manuscript received by the Institution on 15th December 1961 (Paper No. 731).

The 1962 Royal Society Conversazione

Several of the exhibits at this year's Conversazione of the Royal Society, held at Burlington House, London, on 10th May, were of considerable interest to radio engineers. The following details have been supplied by courtesy of the Royal Society.

THE N.P.L. MEKOMETER

Since the speed of light is constant for a given atmospheric condition the distance between a source of light and a mirror can be found by measuring the time taken for a flash of light to travel to the mirror and back again. Instruments designed on this principle are already used in geodetic survey work, but they are sensitive to background illumination, while the Mekometer developed by Dr. K. D. Froome and Mr. R. H. Bradsell operates on the principle of polarization modulation and can be used in full sunshine.

A beam of light is passed through a special crystal (ammonium dihydrogen phosphate) whose optical properties change when an electric field is present. The instrument uses an alternating field of about 10 Gc/s. When the light passes through the crystal in the presence of this alternating field, it emerges with its polarization properties varying at the microwave frequency. It is then sent over the distance to be measured and reflected back again through the crystal. An examination of the polarization of the resulting mixture of the light indicates the distance it has travelled to a high degree of accuracy, approaching the accuracy with which we know the speed of light, namely, one part in a million.

A simplified version of this instrument could be applied to rapid and precise measurement of large engineering structures such as bridges, dams, aircraft-jigs, and nuclear particle accelerators. It should be very much more rapid and permit greater accessibility than the conventional steel or invar measuring tape.

THE OPTICAL MASER

The distinctive features of the beam of coherent light produced by an optical maser are its high intensity in a single direction, and the purity of its colour: its electromagnetic waves are almost continuous and uniform, like radio waves and unlike light from any other source. For communications purposes, it is the extreme purity of continuously operating gaseous devices which is especially attractive but at the National Physical Laboratory attention is being concentrated on solid state devices which produce light of very great intensity in short pulses.

Light is produced by an atom when its structure alters through one of its electrons falling from a state of higher energy "downstairs" to one of lower energy. The greater the energy jump the shorter the wavelength of the light, that is, the further in the blue end of the spectrum. Similarly, when light passes through a body some of its energy is used in lifting electrons "upstairs" to a higher energy level, and light of the corresponding wavelength is absorbed. This is the origin of colour. In the maser a way is found to lift the electrons in the atoms to the higher energy state. Then when light of just the right frequency falls on the maser it triggers off all these high-energy state atoms and the body emits an intense flash of light of very pure colour.

The maser exhibited by Dr. J. M. Burch and Messrs. J. W. C. Gates and R. W. E. Cook consists of a synthetic ruby rod with partly reflecting parallel ends, which is illuminated with white light from a high-power flash tube. Electrons in the chromium atoms which give ruby its characteristic colour absorb some of this light, which is then re-emitted and reflected backwards and forwards between the end-mirrors. Under these conditions, a process known as "stimulated emission of radiation" occurs: the electrons release their excess energy and a light beam emerges as a brilliant red flash lasting from a microsecond to a millisecond. To produce light of equivalent intensity, an ordinary light source relying on spontaneous emission would have to be at 10^{12}°K—a temperature achieved only in thermo-nuclear explosions. When focused to a small spot, a single flash will burn a hole through a steel razor-blade. More serious experiments exploiting the intensity of maser light include high-speed photography of ultra-microscopic particles, and generation of ultra-violet light by shining the red beam from the maser on to a quartz crystal.

JUMP RECORDING PLATFORM

In studying the properties of living muscles it is usual to measure how hard they can pull and how quickly they can move. These measurements are usually made with a range of loads for the muscles to work against. By these and other similar measurements it is possible to specify in some detail the mechanical properties of a muscle under experimental conditions. A piece of apparatus shown by Dr. R. H. J. Brown of the Department of Zoology, University of Cambridge, is designed to find out how such properties are used in an intact live animal. Knowing the lever systems at the joints of the legs, the weight of the animal, and from the springboard, the magnitude, duration and direction of the force exerted at the feet, one can estimate the forces actually being produced by the muscle. It emerges that the locust when jumping uses a very fast (1/50th second) contraction; and that in a locust weighing about 3 grammes, each leg muscle develops a tension up to 1200 grammes weight. The acceleration is linear and about 12 *g*. There is reasonable agreement with measurements derived from high-speed photographs.

The platform is carried on two hardened steel bars which allow it to move slightly either vertically or horizontally. Mounted below and at one side are capacitive transducers which respond to vertical or horizontal movements of the platform. The capacitance of these transducers can be varied by deflecting one of the plates. These form the tuning capacitors for a pair of high frequency oscillators, and as they are moved so the frequency changes. This change is measured and displayed as a deflection on an oscilloscope. The deflection can be calibrated by applying known forces to the platform. The total movement is less than 1/1000th of an inch and the response time of the platform is about 1/800th second.

NOMINATIONS FOR ELECTION TO THE COUNCIL OF THE INSTITUTION

In accordance with Bye-Law 43, the Council has nominated the following members for election at the next Annual General Meeting which will be held in London on 24th October 1962.

The President

Admiral of the Fleet the Earl Mountbatten of Burma, K.G., has consented to be nominated for re-election as President.

The Vice-Presidents

For Re-election:

J. L. Thompson
L. H. Bedford, C.B.E., M.A., B.Sc., F.C.G.I.
Professor E. E. Zepler, Ph.D.
Professor Emrys Williams, Ph.D.
W. E. Miller, M.A.
Colonel G. W. Raby, C.B.E.

(Air Vice-Marshal C. P. Brown, C.B., C.B.E., D.F.C., does not seek re-election because of ill health.)

For Election:

A. A. Dyson, O.B.E. First elected a member of the Council in 1958, Mr. Dyson has been a member of the Finance Committee since 1960 and a Trustee of the Benevolent Fund since 1957.

The Honorary Treasurer

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

Ordinary Members of the Council

Dr. A. D. Booth has resigned from the Council on his appointment to the Chair of Electrical Engineering at the University of Saskatchewan, Canada.

Mr. A. A. Dyson has been nominated for election as a Vice-President.

Because of pressure of other Institution work, Professor D. G. Tucker, D.Sc., Ph.D., and Mr. F. G. Diver, M.B.E., will retire from the Council at the next Annual General Meeting.

The Council nominates the following Members to fill the four vacancies:

Brigadier L. H. Atkinson, O.B.E., B.Sc., who was elected a Member of the Institution in 1957 and has been a regular member of the Education Committee since 1959. He is Commandant, R.E.M.E. Training Centre, Arborfield.

A. G. Wray, M.A., who was elected an Associate Member in 1952 and transferred to the class of Member in 1961. He has been a regular member of the Programme and Papers Committee since 1953 and has been appointed Chairman of the Committee in succession to Dr. A. D. Booth. He is deputy chief engineer of Marconi Instruments Limited.

J. R. Brinkley. Elected an Associate Member in 1948 and transferred to the class of Member in 1952, Mr. Brinkley is managing director of Pye Telecommunications Limited.

A. St. Johnston, B.Sc.(Hons.), A.C.G.I., was elected a Member of the Institution in 1960 and is the Institution's representative on the British Conference on Automation and Computation. He has also been a member of the Computer Group Committee since 1960. Mr. St. Johnston is joint managing director of E-A Data Processing Limited.

Bye-Law 42 permits the election of three Associate Members to the Council, and at present there are only two. The Council is anxious that this class of member shall be fully represented and for the vacancy nominates:

W. A. Gambling, Ph.D., B.Sc., who was elected an Associate Member in 1958. Dr. Gambling was Chairman of the Southern Section in 1961–62 and is senior lecturer in the Department of Electronics, University of Southampton.

Under Bye-Law 42 not more than one Ordinary Member of Council shall be chosen from the classes of Companions and Honorary Members.

Mr. A. H. Whiteley, M.B.E. (Companion), has served on the Council since 1953 and has intimated his wish to retire though he will continue to serve on the Finance Committee.

Mr. E. K. Cole, C.B.E., Honorary Member representative on the Council, also wishes to retire from office.

The Council nominates:

J. N. Toothill, C.B.E. Elected a Companion in 1958. Mr. Toothill is general manager of Ferranti Limited, Edinburgh.

Bye-Law 44 provides that:

Within twenty-eight days after the publication of the names of the persons nominated by the Council for the vacancies about to occur any ten or more Corporate Members may nominate any one other duly qualified person to fill any of these vacancies by causing to be delivered to the Secretary a nomination in writing signed by them together with the written and signed consent of the person nominated undertaking to accept office if elected, but each nominator shall be debarred from nominating any other person for the same vacancy.

By Order of the Council

27th June 1962

GRAHAM D. CLIFFORD, *Secretary*

# of current interest . . .

Telefis Eireann

Experimental 405-line transmissions began from the first Irish television station on 5th September 1961 at Kippure just south-west of Dublin. The full programme service was inaugurated on 31st December.

In August it had been announced that Irish television will eventually work on a 625-line standard, but in the north of the country 405-line is being transmitted as there are already many receivers intended for the B.B.C. and I.T.A. programmes from Northern Ireland.

Besides Kippure, four other major transmitters are being planned at Truskmore, near Sligo, Maghera near Limerick, Mt. Leinster, near Waterford, and Mullagarish, near Cork, and should commence operation before the end of 1962. A temporary station is to be provided to serve Cork until the permanent station at Mullagarish is ready.

Kippure transmits on Channel B7 with a maximum vision e.r.p. of 100 kilowatts. It is 2473 ft a.s.l. and the aerial is 300 ft high; the radiated power for vision is 50 kW and sound 12·5 kW. The sound and vision frequencies are 181·25 Mc/s and 184·75 Mc/s respectively. Polarization is horizontal.

It has also been announced that Kippure will soon start 625-line transmissions and that when the Truskmore station opens it too will be dual-standard. The proposed 625-lines system was assigned 8 Mc/s channels in Bands I and III by the E.B.U. in 1961.

Research in Schools

The Royal Society Committee on Scientific Research in schools has announced that during 1960–1 63 separate scientific investigations were being conducted with the support of the Royal Society by science teachers in schools throughout the country. Although some financial assistance is given, the scope of these projects is limited by the resources in the schools.

The majority of the teachers in the scheme are engaged on research into biological and chemical subjects, but a few are at work studying electrical phenomena. At Tregaron County Secondary School, Cardiganshire, work is being done on the measurement of ionospheric drifts, while the Ipswich School, Suffolk, is conducting studies of "whistler" atmospherics. Research on radio-astronomy is being undertaken at the Westminster School, London. Investigations into paramagnetism and ferromagnetism are being made at Marlborough College and the Thorpe Grammar School, Norfolk, respectively. So far the scheme has met with an encouraging degree of success and resulted in the publication of four papers in leading technical journals during the previous year.

Technology at Bangor

There is an increasing awareness of the need for the re-appraisal of engineering subjects in universities. At the University College of North Wales, Bangor, there has been for some time a Department of Electronic Engineering, and since the opening of a new building in 1959 the Department has been expanding rapidly. Plans are now being made and implemented for further and wider technological development and it is proposed to set up a Department of Applied Science with three closely integrated sub-departments of Electronic Engineering, Control Engineering and Materials Technology. All engineering undergraduates reading for the B.Sc. degree will spend some time in each of these sub-departments and at this stage the courses will be concerned mainly with general principles of applied science. It is intended to provide opportunities for further study and some specialization after the first degree by offering M.Sc. courses in these subjects.

The existing department of Electronic Engineering, under Professor M. R. Gavin (Member), has been providing a degree course for many years in electronic engineering, which has been closely linked with physics and mathematics. It is well-established with an intake of about 50 students per year and it will continue to provide the basic electrical science of the new course.

The primary function of the sub-department of Control Engineering will be to provide a basic course in engineering science. It is believed that the study of the principles of control can provide an excellent discipline in which a wide range of technological phenomena can be illustrated and integrated. For this purpose control engineering is essentially concerned with a study of the response of a wide variety of systems. Some study of control is already included in the degree course and it is intended in due course to create a Chair of Control Engineering.

In studying the subject of Materials Technology the course will draw on the methods of physics, chemistry, metallurgy and engineering, as and when appropriate, but the whole treatment will be integrated in terms of modern theory of solids and in the light of technological needs. In the early stages the main emphasis will be on electrical materials as there is already at Bangor some considerable electrical background with a strong research effort on applied semiconductors. Later on, when the present plans have been fully realized and consolidated, there should be a widening of the course to include other aspects of materials. A major step forward in these developments is the appointment of Dr. R. W. Cahn to the newly-created Chair of Materials Technology.

TRANSISTORIZED TELEVISION RECEIVERS

Proceedings of a Television Group Discussion Meeting held in London on 6th April 1961

U.D.C. 621.397.621.54:621.382.3

Tuners for Transistorized Television Receivers

By J. K. BROWN†

1. General Requirements

The general requirements of a tuner unit for television reception, whether transistorized or conventional valve type, are that by some mechanical operation various coils related to a channel are inserted into the electrical circuit to provide adequate selectivity and gain for the particular channel it is selected to receive; the unit must provide an adequate match to the aerial with as low a noise figure as possible, and include a local oscillator and mixer circuit to convert incoming frequencies to a common i.f. for amplification by the succeeding i.f. amplifiers; the oscillator must have low frequency drift with varying temperatures, and in the case of transistorized versions, a reasonably low drift with battery voltage variation. Finally, the unit must be capable of gain control from the a.g.c. circuit and include the necessary broadcast filters and i.f. traps.

The unit which will be described here is essentially a transistorized version of a tuner originally designed for frame grid valves. All mechanical aspects have been maintained and while it is undoubtedly possible that a tuner designed around transistors can be made a lot smaller, this mechanical arrangement has proved excellent for experimental work.

An interesting feature is the use of the transistor holders. This adds to the expense of the tuner, of course, but it has enabled a great deal of information to be gathered on the characteritics of many transistors in the same tuner and many tuners with the same transistors. Also, the holders enable the wiring to be kept much more consistent—a factor of importance in successful tuner production—and the arguments for their retention are considerable.

2. Circuit Description

Referring to Fig. 1 the signal is first filtered by the series and parallel i.f. traps and broadcast filter into the series-tuned circuit formed by the blocking capacitor C3, the coil L1, which is switched for each channel, and the input capacitance and resistance of the transistor VT1, operating under common emitter conditions. Input capacitance and resistance vary

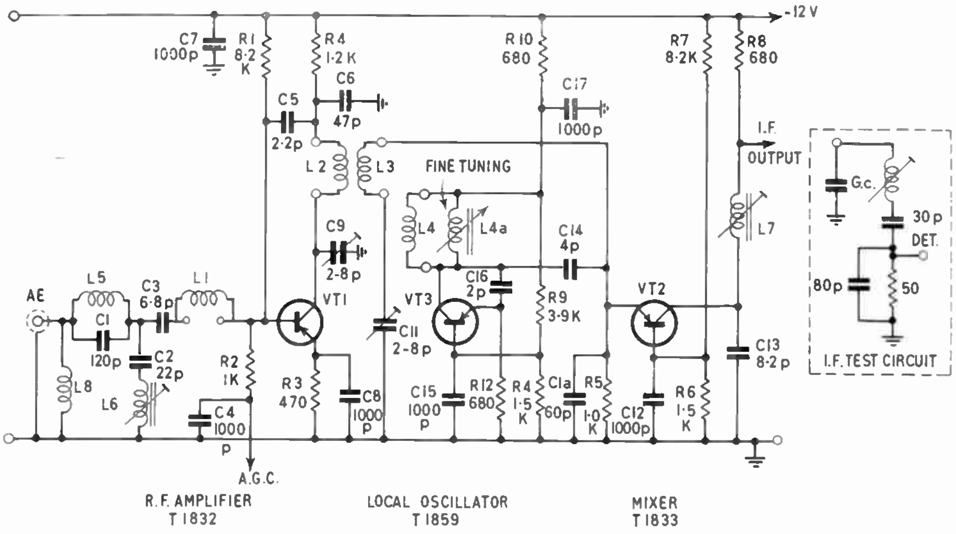

Fig. 1. Three transistor television tuner.

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† A.B. Metal Products Ltd., Abercynon, Glamorgan.

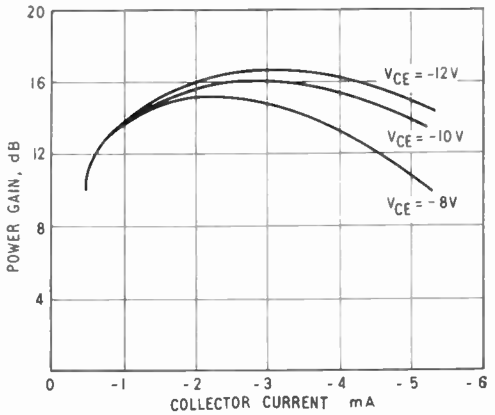

Fig. 2. Typical gain/collector current characteristic for T.1832 transistor in 200 Mc/s amplifier test circuit.

widely over the range of frequencies 50–200 Mc/s and figures of 200 ohm and 15 pF at 50 Mc/s and 60 ohm and 2 pF at 200 Mc/s are quoted, but it is found in practice and substantiated by a theoretical conclusion that these combinations approach a match to 75 ohm with the circuit shown. Matching with this tuner appears to be much better than the best obtainable with a valve operated with the single aerial coil system, and furthermore the best power match and the best noise match for the transistor appear to be coincident.

Common emitter operation appears better than the common base in respect to matching because the input resistance in a common base is quoted as varying from 30 ohm at 50 Mc/s to 150 ohm at 200 Mc/s. This makes matching more difficult and this fact, combined with a natural regeneration of the common base arrangement at these frequencies, makes a neutralized common emitter system the preferable arrangement. Resistors R1, R2, R3 provide the necessary stabilization network with R4, C5 and C6 the general neutralization arrangement. Figure 2 is a plot of power gain versus collector current under different collector emitter voltages, and it can be seen that optimum gain exists between 2 and 2·5 mA; increasing the current and reducing the voltage results in lower gain. This characteristic of the transistor is used on the tuner for automatic gain control, and referring again to Fig. 1, it is seen that if a negative voltage is applied to the lower end of R2 which is brought out for a.g.c. purposes, the collector current increases, the voltage drop across R4 and R3 increases, resulting in a reduced collector voltage and lower gain. This action constitutes the forward a.g.c. of the tuner.

The output of the r.f. stage is tuned by the collector coil L2 which is switched for each channel and inductively coupled to the emitter of the mixer transistor VT2 which is operating under common base conditions. The mixer input circuit is tuned by coil L3 which is also switched for each channel, and L2 and L3 provide a bandpass of the correct bandwidth for reception. C11 and C10 serve to match the input impedance of the mixer to the output resistance of the preceding r.f. stage and base biasing is accomplished in a similar way to the r.f. stage.

Oscillator voltage is injected capacitively to the mixer emitter by the capacitor C14, and the collector of the mixer transistor is connected to the usual bottom capacitance i.f. coupled circuit, only the primary of which is given in the tuner.

The choice of common base configuration in the mixer is mainly dictated by the low input impedance at i.f. Work carried out on common emitter mixers indicates a severe degenerative feedback on Channel 1 causing distortion in the r.f. bandpass response characteristic and although an i.f. trap in the common emitter input reduces this effect, investigations on this supposed possibility are far from complete.

The oscillator transistor is operated in a common base arrangement with the oscillator coil L4 forming a tuned circuit with the transistor capacitances and an extra feedback capacitor of 2 pF connected between emitter and collector.

3. Performance of the Tuner

3.1. *Gain*

Power gain is measured from the aerial terminals to the secondary of the i.f. output transformer, the latter being terminated by 50 ohms and 80 pF to represent the usual input impedance of the first i.f. transistor amplifier. Gain spreads of between 29 and 35 dB are obtained on Band I and between 19 and 25 dB on Band III. This difference between Band I and Band III gains with transistors presently available represents a problem compared with the valve tuners where the

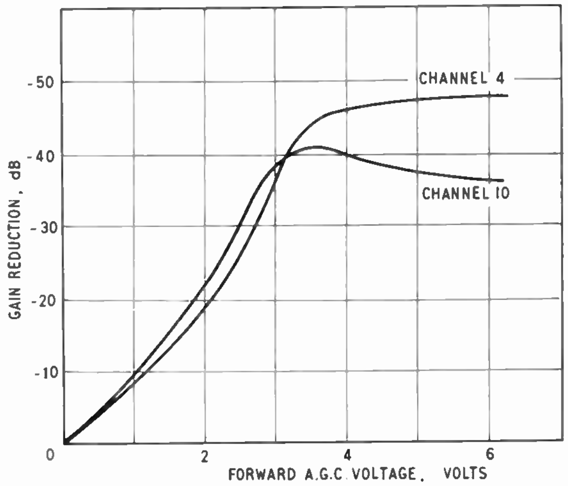

Fig. 3. Typical a.g.c. characteristic.

deviation can be brought down to 2 or 3 dB. Gain variation with battery voltage is about ½ dB per volt in the region 10–14 volts.

3.2. *Noise*

Noise measurements are as follows:

Band I	average 6·5 dB
Band III	average 7·5 dB

The transistor tuner, therefore, can be said to correspond closely in noise figure to valve versions.

3.3. *A.G.C. Characteristics*

The a.g.c. characteristics are shown in Fig. 3. Application of up to 2 volts to the a.g.c. terminal results in a fairly linear attenuation to 20 dB for both Band I and Band III.

3.4. *Drift*

As far as oscillator drift is concerned, the drift with battery voltage is shown in Fig. 4. On both Channel 1 and Channel 9 there is a variation of something like 150 kc/s per volt. Drift with temperature can be an important factor, particularly in sets operated out of doors in sunshine, and less consistency in drift figures is found than in the conventional valve tuner. Some temperature compensation can be given, however, and present results indicate that the drift with a change of temperature of ±25 deg F from a nominal 70° F can be kept within ±200 kc/s.

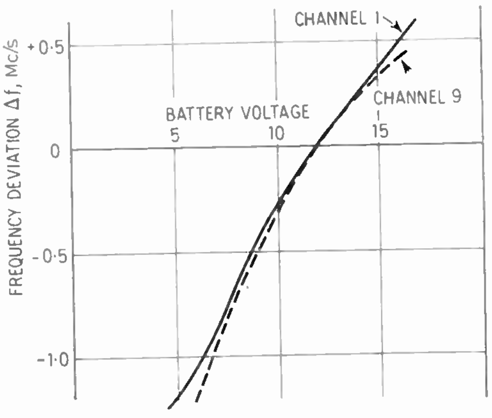

Fig. 4. Oscillator frequency shift vs. battery voltage.

Manuscript received by the Institution on 5th June 1961. (Contribution No. 48.)

U.D.C. 621.397.621 : 621.375.4

Transistorized I.F. Amplifiers for Television Receivers

By E. G. CHARDIN†

1. Design Considerations

The introduction of various types of alloy-diffused transistors capable of providing useful gains at frequencies up to 100 Mc/s and above has made it feasible to design, and produce, television intermediate-frequency amplifiers for receivers to give an overall performance similar to that which can be provided by valves.

Since it is likely that a transistorized television receiver would be required for portable use, with small aerials, the receiver should be capable of providing a useful picture with signals at the aerial terminals as low as about 20 μV. The voltage level at the vision detector to provide full drive for a transistor video amplifier is about 1 volt and hence the overall gain is required to be about 94 dB. On the sound side the audio amplifier input required is some 10 dB lower than this. Assuming a practical figure of 24 dB for the tuner, the two amplifier chains require to have gains of at least 70 dB and 60 dB respectively.

By comparison with valve amplifiers where the gain of the narrow sound i.f. stages tends to be higher than the vision stages, one finds that with transistors, practical circuits tend to produce sound amplifier gains which are slightly lower than the broadband vision stages.

To a first approximation, the minimum bandwidth that one can obtain for a pair of valves coupled by a tuned circuit at 36 Mc/s, (assuming stray capacitances of about 15 pF and a total circuit resistance of 10 kΩ), is about 1 Mc/s with practical coils. Thus for the sound i.f. coils where an overall bandwidth of the order of 600 kc/s is required, the whole natural gain of the stage may be utilized. However, for the vision stages where an overall bandwidth of some 3 Mc/s may be required one must resort to overcoupled or damped tuned circuits or both, to obtain the necessary stage bandwidths. This means that the gain of the individual vision amplifiers will tend to be lower than the sound amplifiers.

With coupled transistor amplifiers the situation is very different. Here the total circuit resistance is of

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† Pye Ltd., Cambridge.

the order of 1·5 kΩ, (for a correctly matched coupled pair), and if one assumes a similar tuning capacitance of 15 pF the natural bandwidth of the circuit is about 6·7 Mc/s. This order of bandwidth is quite usable for the vision amplifier stages, but is impossibly wide for, say, each of three sound i.f. stages.

In order to narrow the stage bandwidths for the sound i.f. amplifiers one must resort to raising the tuning capacitance in order to lower the dynamic resistance of the tuned coupling circuit and thereby modify the serious reduction in working Q imposed by the transistors. To restore the desired bandwidth of 1 Mc/s at 36 Mc/s the total tuning capacitance must be raised considerably. However, the very act of lowering the L/C ratio of the tuned circuit implies the introduction of a loss element of resistance in the coupling of some 5 kΩ. Practical amplifier stages will produce power gains of the order of 20–22 dB as vision i.f. amplifiers and some 18–20 dB as sound i.f. amplifiers.

2. Circuit Arrangements

Until entirely satisfactory i.f. and tuner a.g.c. arrangements can be developed it appears desirable to use independent sound and vision i.f. amplifier chains if cross-modulation difficulties are to be avoided. Unfortunately, with most types of r.f. transistor where a.g.c. is achieved by control of the base current only, a limited amount of gain reduction is possible and the signal handling capacity becomes small with consequent danger of cross-modulation if both vision and sound signals are applied to it. Eventually, the use of auxiliary a.g.c. controlled devices such as "damping" diodes may allow common i.f. amplifier stages to be used. Thus, three or possibly four transistors for each chain are required at present for each i.f. amplifier to obtain the required overall gains of 60–70 dB.

Since the six to eight stages of the i.f. amplifiers will require a similar number of tuned circuits there is considerable latitude in the response shaping methods used. While band-pass pairs can be arranged to give excellent characteristics the transformers tend to be large and the problems of coupling quite difficult with low circuit impedances involved. For the same reasons inter-stage trap circuits are to be avoided—it being more satisfactory to insert these in the coupling between the tuner and the i.f. amplifiers.

It may therefore be worth while to consider the use of simple single tuned coupled circuits both for sound and vision amplifiers.

3. Stages in Development

The transistor stages in the vision and sound i.f. amplifiers are basically similar, and in order to establish suitable circuit parameters for the stages it is helpful to construct an experimental amplifier stage using the chosen transistor. Figure 1 depicts such an amplifier together with the main design steps necessary. Once the basic amplifier requirements are known it is a relatively simple matter to adjust the inductance and

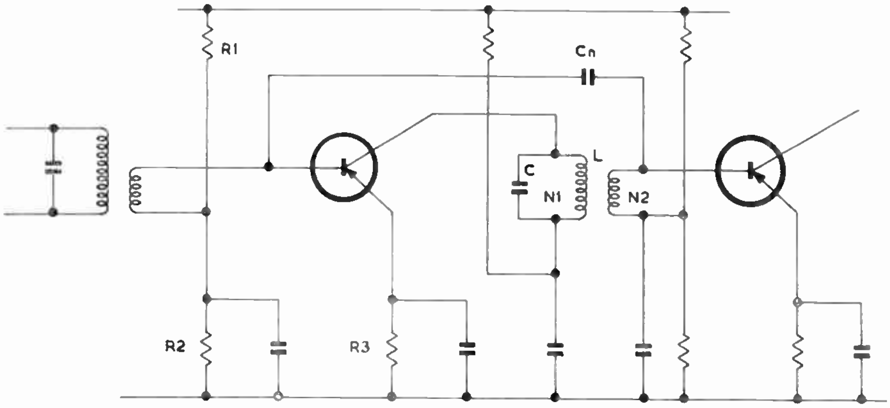
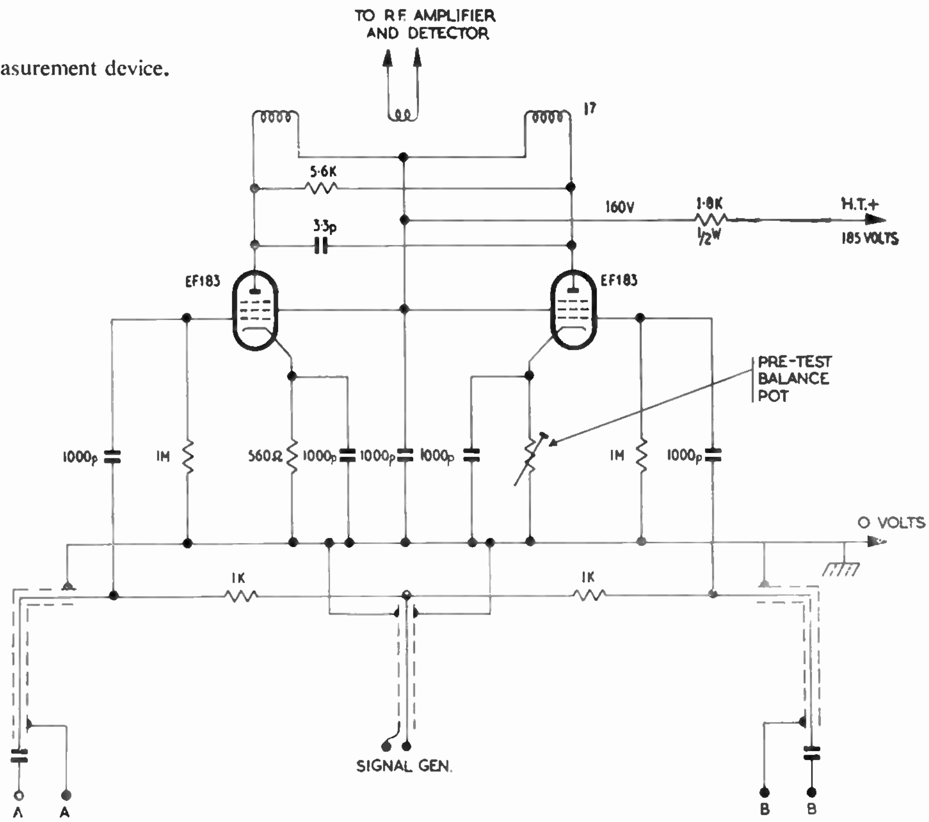


Fig. 1. Stages in design.[†]

1. Determine h.t. supply voltage and working current for transistor.
2. Check that with desired emitter current the transistor is operating within maximum collector dissipation.
3. Establish suitable values for R1, R2 and R3 to effect d.c. stabilization.
4. Determine input and output impedances to transistor at working current.
5. Calculate $Q_{\mathrm{wkg.}}$, L, C and the turns ratio for the transformer for correct matching and bandwidth.
6. Neutralize stage.

[†] L. E. Jansson, "High frequency amplification using junction transistors", *Mullard Tech. Commun.*, 3, No. 26, October 1957. S. W. Amos, "Principles of Transistor Circuits", (Iliffe, London, 1959).

Fig. 2. Transistor impedance measurement device.



capacitance values and the matching ratios for any desired stage bandwidth.

Neutralization is desirable in each stage to reduce the interdependence of tuning between the coupling circuits and unless the circuit is designed with a very high stability factor, the use of neutralization can provide useful improvements in gain in each stage.

Since it is a difficult matter to make measurements of the behaviour of the basic transistor circuit within the amplifier itself the device shown in Fig. 2 has proved to be a useful design tool.

The instrument consists of two valve amplifiers sharing a common input from a signal generator and whose outputs feed a common detector device in such a manner that a null indication is obtained from the detector when the two amplifier gains are balanced and equal components of impedance are connected to the terminals AA and BB. Once the amplifier gains have been balanced, the terminals AA may be connected to the input or output circuits of the experimental transistor i.f. amplifier. The effective components of the input and output circuit impedances and their variations with transistor working conditions may then be studied by connecting external components of impedance to the terminals BB to restore amplifier balance. These external components may then be measured with some accuracy.

4. Neutralization

Various methods of neutralization are in common use and four possible arrangements are shown in Fig. 3.

In method (*a*) a small extra winding at the earth end of the main tuned winding provides the anti-phase neutralizing voltage. This method has the advantage that it is easy to adjust, and allows for the use of similar neutralizing capacitors throughout the i.f. amplifiers.

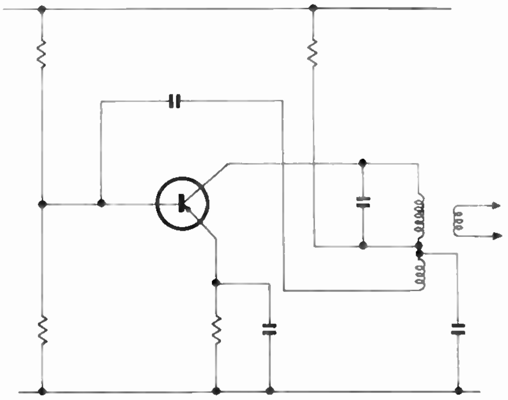


Fig. 3(*a*). Methods of neutralization.

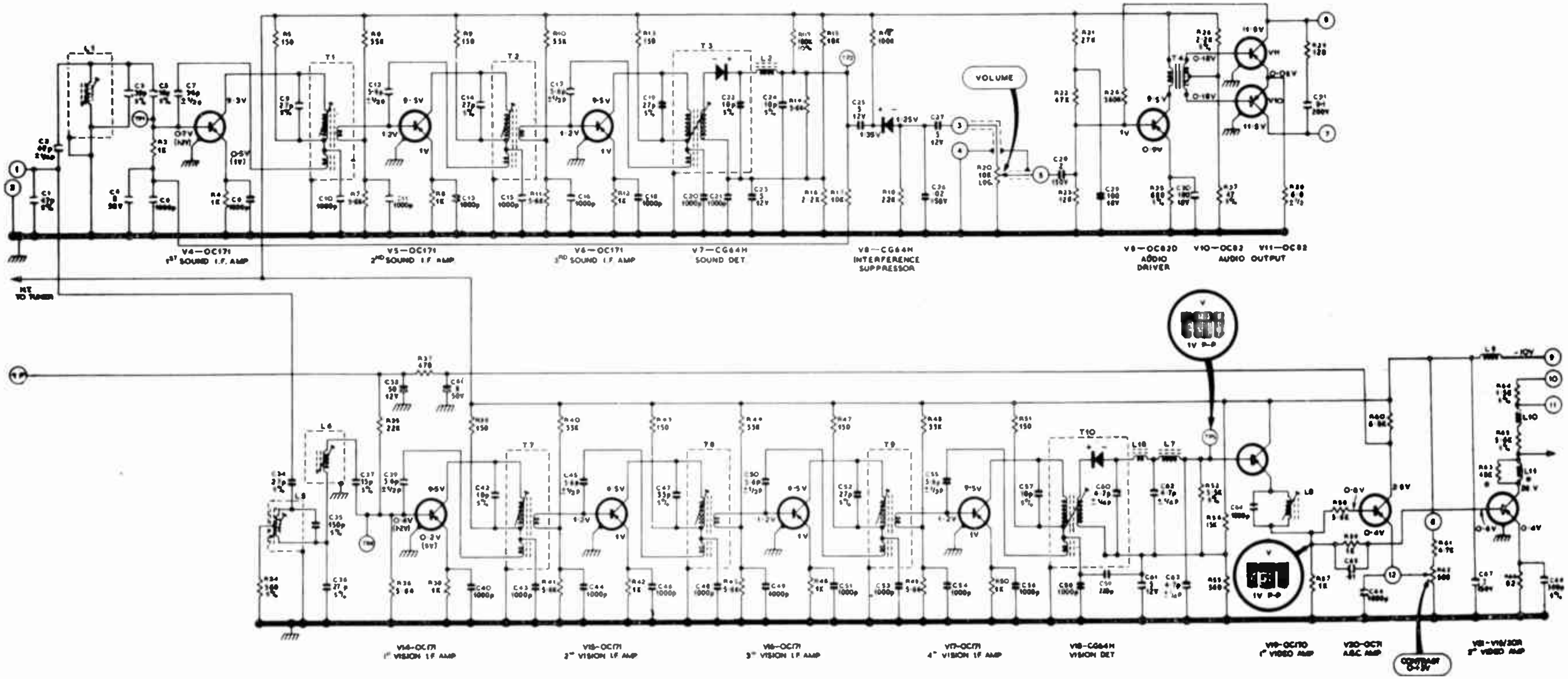
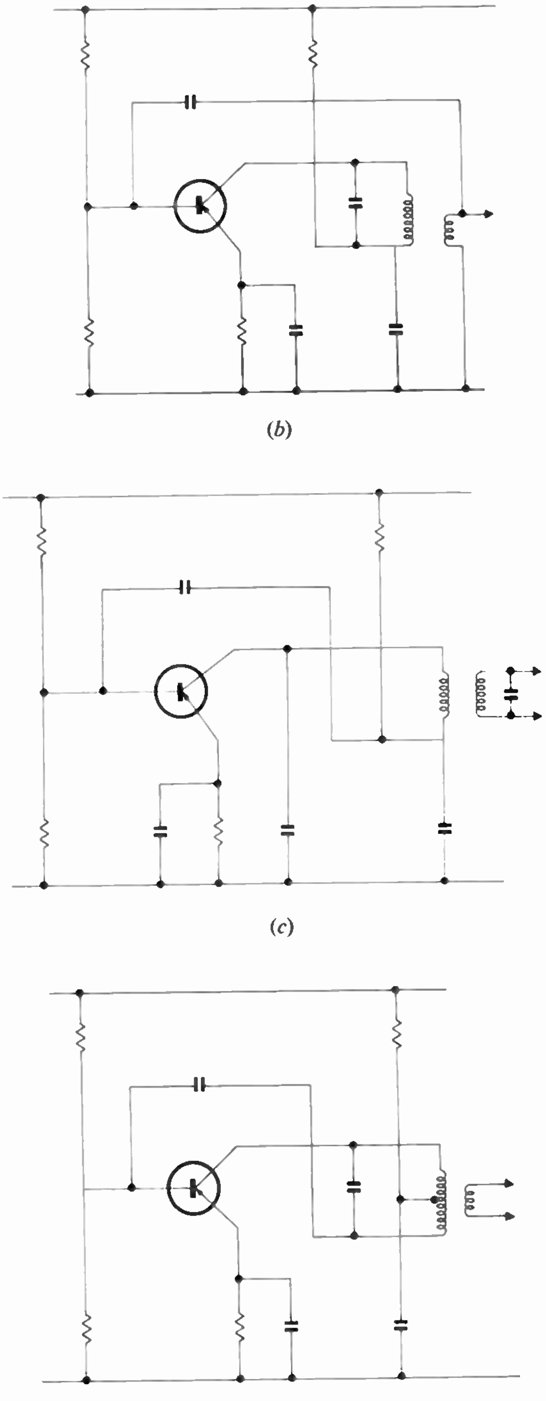


Fig. 4. I.F. amplifier for transistorized television receiver.

In method (*b*) the base winding of the following stage is itself used to provide the anti-phase signal and the method is very effective and cheap since only four coil terminals are required. In this case it is necessary to reverse the sense of the secondary connections with respect to the primary winding.


(*b*)

(*c*)

(*d*)

Fig. 3. Methods of neutralization.

Where bandpass transformers are used the neutralizing circuits (*c*) and (*d*) are useful. The tapped capacitance method is preferable since taps on small coils are awkward to arrange, particularly if tuning cores are used in the coils.

5. A Complete Circuit

Figure 4 is the complete circuit diagram of the i.f. amplifiers of a transistor television receiver, together with the audio and video amplifiers. A single printed circuit board contains the whole circuit, and simple miniature coils are used throughout. On the vision side four transistors are used and the shaping of the amplifier response is achieved by using broad bandwidth circuits at the 1st i.f. stage and detector with relatively narrow bandwidth circuits in the intermediate stages. These are tuned near the edges of the i.f. pass band. The bottom capacitance coupling between the tuner and the i.f. amplifier is conventional and a bridged-"T" sound i.f. rejector circuit is inserted in this coupling. Three stages only are used in the sound i.f. amplifier since the drive requirements for the audio amplifier are considerably less than for the video amplifier. In both vision and sound i.f. amplifiers the neutralizing method (*a*) of Fig. 3 has been used.

Reverse a.g.c. is used on the first stages of the sound and vision i.f. amplifiers and "contrast" control for the vision channel is achieved by altering the delay bias potential at the emitter of the vision a.g.c. amplifier. The total power consumption of the i.f. amplifier and its associated tuner is 240 mW from an h.t. supply of 10 V.

It is interesting to note that this h.t. power input is only about one fiftieth of that required for a valve receiver of equivalent aerial sensitivity.

6. Future Developments

Complete i.f. amplifiers using only six or even five transistors appear to be quite feasible for future receivers, and once the problems of a.g.c. can be solved, the use of at least one common vision and sound i.f. amplifier is attractive. Circuit arrangements using a positive h.t. supply rail may offer some advantages in economy of collector decoupling components.

7. Acknowledgment

Thanks are due to the Directors of Pye Limited for permission to publish this paper.

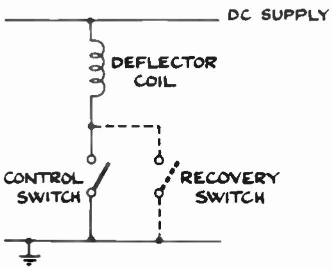
Manuscript received by the Institution on 5th June 1961. (Contribution No. 49.)

U.D.C. 621.397.332:621.382.3

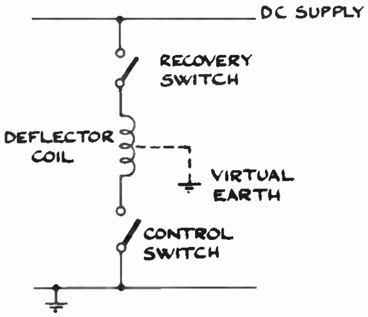
Line Time-Base Circuits for Transistor Operation

By R. W. A. SCARR, B.Sc.(Eng.), Ph.D.†

Magnetically deflected line time-bases consist of a coil that is a fairly good approximation to a pure inductance and one or two switches. When there are two switches, one switch is usually a three-terminal device, and the other a two-terminal device. The need for two switches only arises because most of the three-terminal switches available to the designer are unilateral devices. With a bilateral device, the number of switches can be reduced to one. But in either case, there must be one switch that can be turned on and off with a relatively small signal.



(*a*) Shunt recovery.



(*b*) Series recovery.

(*c*) Voltage waveforms across deflector coil.

Fig. 1. Basic time-base circuits.

Figure 1 (*a*) shows the basic arrangement for a shunt recovery circuit in which the use of a bilateral device is possible. Figure 1 (*b*) shows the series arrangement; here a bilateral switch is not possible.

One has the choice of turning on the control switch during the scan (mode 1) or during the flyback (mode 2). It is established practice in the case of valves to turn on the switch during the scan. With transistors we must reconsider this.

The advantage of turning on the switch during the scan (mode 1) is greater linearity control if the control switch is a linear amplifier (as opposed to a two-state device).

The advantage of turning on the control switch during the flyback (mode 2) is low dissipation in the control switch.

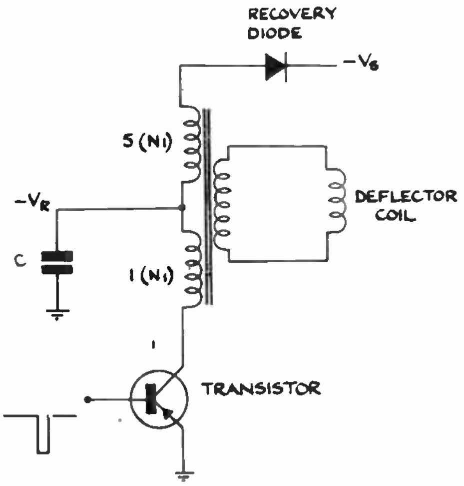


Fig. 2. Realization of Fig. 1(*b*).

Another factor that influences the choice of circuit is the relationship between the supply voltage (as boosted by the recovery circuit) to the maximum rating of the control switch. If the boosted supply is nearly equal to the maximum collector rating of the transistor that we are using as the control switch, then the adoption of mode 2 is indicated.

An example of transistor circuit working in mode 2 is shown in Fig. 2. This corresponds to the basic circuit of Fig. 1 (*b*).

During the flyback, the transistor is conducting, and the voltage across the winding N_1 is equal to the

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† Standard Telephones and Cables Ltd., Transistor Division, Footscray, Sidcup, Kent.

flyback voltage (i.e. this is related to the peak voltage the transistor will withstand). The diode has to withstand a p.i.v. of N_2/N_1, i.e. several times that of the transistor. During the scan, the transistor is cut off, and we have to design the recovery circuit to give the linearity that is needed. To the first approximation this can be done by a suitable choice of the value of C. During the scan, C is being charged by the recovery diode, and the voltage across it is rising. This change in voltage is of the right sense to give the sloping top needed to compensate for the resistance of the deflector coils. However, a simple theoretical analysis of the circuit shows that there may still be a significant departure from linearity. If losses in the recovery diode are taken into account, this non-linearity is reduced; and in practice, by a suitable choice of C, acceptable linearity can be obtained. The transformer must be designed to minimize the leakage inductance between N_1 and N_2. This is very important. Figure 3 shows the arrangement of Fig. 2 in somewhat greater detail.

As the transistor is simply used as an on/off device, the circuit can be converted to a synchronized blocking oscillator (and this has been made to work). A frequency control is a problem, as is synchronization. Of course the transistor could be replaced by a thyratron device, e.g. a *p-n-p-n* controlled rectifier, provided it was (a) fast enough (b) could be turned off, as well as on.

An example of transistor working in mode 1 is shown in Fig. 4. This corresponds to the basic circuit of Fig. 1 (*a*).

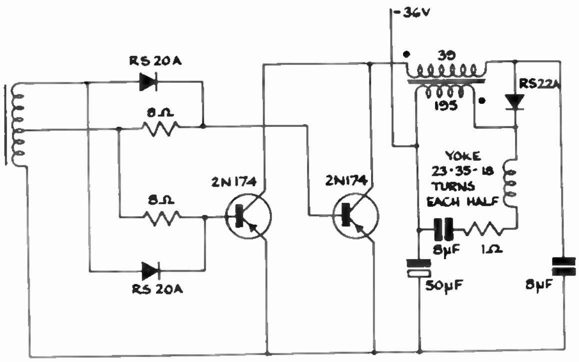

Fig. 3. Practical arrangement of Fig. 2.

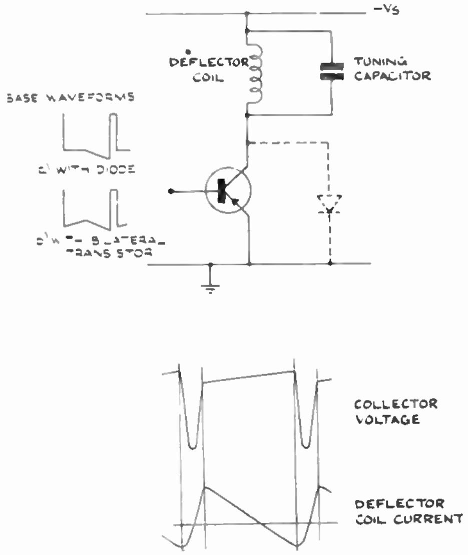

Fig. 4. Realization of Fig. 1 (*a*).

Table 1

	Switching Elements	$\frac{I_{PT}}{I_{PC}}$	$\frac{I_{PD}}{I_{PC}}$	V_{PT}	V_{PD}	$\frac{I_{PT} \cdot V_{PT}}{I_{PC} \cdot V_{PC}}$
Mode 1 (Fig. 4)	1 or 2	1	1	$\sim 8V_S$	$\sim 8V_S$	0·5
Mode 2 (Fig. 2)	2	2	< 1 e.g. 0·6	free choice	$> V_{PT}$	1·0

	Transformer	Thyratron-like Device	Tuned Deflector Coil	Scan Linearity Control
Mode 1 (Fig. 4)	only if e.h.t. required	no	yes	flexible, lossy
Mode 2 (Fig. 2)	yes	possible	no	inflexible less lossy

I_{PT}, I_{PD}, I_{PC} are peak currents in the transistor, diode and deflector coil respectively.

V_{PT}, V_{PD}, V_{PC} are peak voltages across transistor, diode and coil respectively.

We can use a bidirectional transistor, or a transistor in parallel with a diode. The re-trace time is determined by the resonant circuit. One half-cycle at the resonant frequency is slightly less than the re-trace time. Difficulties arise in linearizing the scan, and to some extent this can only be done at the cost of efficiency. The peak inverse voltage on the transistor is directly related to the supply voltage.

Table 1 summarizes the characteristics of the two circuits discussed.

Manuscript received by the Institution on 10th July 1961. (Contribution No. 50.)

U.D.C. 621.397.666:621.382.3

Some Transistor Requirements for A.G.C. Operation

By J. R. JAMES (*Associate Member*)†

1. Transistor Characteristics

The analytical approach to transistorized automatic gain control has been well described in the literature[1] as early as 1955 and there have been few additions since.

In practice, the operating point of a transistor is often determined by requirements other than a.g.c. and it is essential to know how the a.g.c. performance varies with the operating point. In this respect the analytical method, although precise, is rather tedious and the need for a quick method of indicating the a.g.c. performance, as a function of the operating point, is very apparent. Such a method is proposed in this note which will give practical circuit arrangements applicable to the American 525-line system.

1.1. f_T *Contours*

Experiment has shown that at frequencies above β cut-off the a.g.c. performance of a transistor can be described by means of a graphical presentation of f_T as a function of collector voltage and collector current. These f_T contours will be referred to as (V, I) curves and a more detailed description of their measurement and uses is given in the literature.[2]

As shown in Fig. 1, f_1 is the frequency at which the modulus of β is unity and f_T is the projected value. This projected value is easier to measure and, since it differs very little from f_1, is generally accepted in place of f_1.

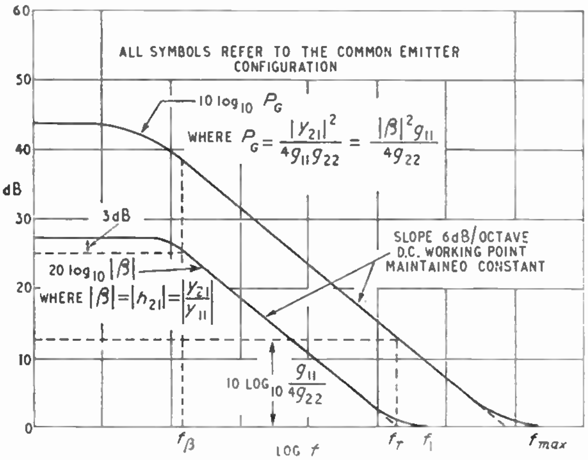

Fig. 1. Frequency response in the common-emitter configuration.

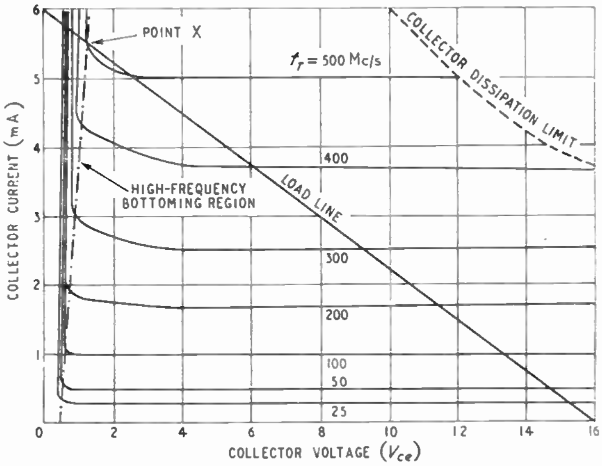

Fig. 2. $f_T(V, I)$ plot of typical switching transistor.

Using the other relationships in Fig. 1, it can be shown[2] that the maximum matched unilateralized power gain P_G is, to a first order, proportional to $(f_T)^2$. Thus the operating point on the $f_T(V, I)$ curves, which produces the highest f_T, also gives the greatest power gain. At any operating point the necessary change in the d.c. conditions to produce a reduction in gain and hence a.g.c. action, is readily seen.

1.2. $f_T(V, I)$ *Curves of a Switching Transistor*

It is not unusual for a switching transistor to be used in an amplifier application. A typical $f_T(V, I)$ plot for a transistor which is a good switch is shown in Fig. 2. In order to achieve a high f_T and hence a large power gain, it is necessary to run the device at a high collector current. A possible operating point for this transistor would be $I_c = 5$ mA, $V_c = 2$ V. This could be obtained from a 16 V supply by inserting a decoupled resistor, of value 2·7 kΩ, in the collector line. If the collector current is increased, the operating point will move along the road line and, at the point X there will be a considerable drop in f_T and therefore gain. This type of a.g.c. is called forward a.g.c. To apply the more usual or reverse a.g.c. it will be necessary to reduce the collector current to almost zero.

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† Formerly Semiconductors Ltd., Swindon, Wiltshire.

Experiment has indicated that the most suitable amplifier application for a switching transistor is as a large signal device, rather than a small signal amplifier with a.g.c. This is also apparent from the $f_T(V, I)$ curves of Fig. 2, where, apart from the high-frequency bottoming region the characteristics are spaced in a linear manner.

1.3. $f_T(V, I)$ *Curves of an Amplifier Transistor*

A typical $f_T(V, I)$ plot for a transistor, such as the Philco 2N1742 which has been specially designed for amplifier applications, is shown in Fig. 3. It is seen that for a collector voltage of 12V there is an optimum collector current of about 1·5 mA. If P_0 is the operating point, P_0 to P_2 along the load line corresponds to forward a.g.c. and P_0 to P_1 to reverse a.g.c.

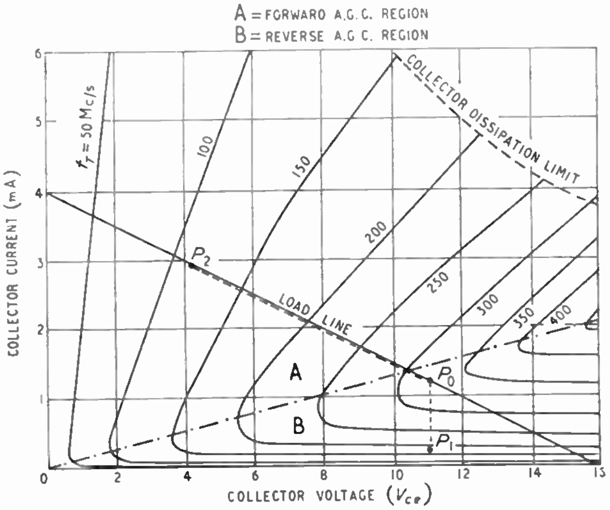


Fig. 3. $f_T(V, I)$ plot of typical amplifier transistor.

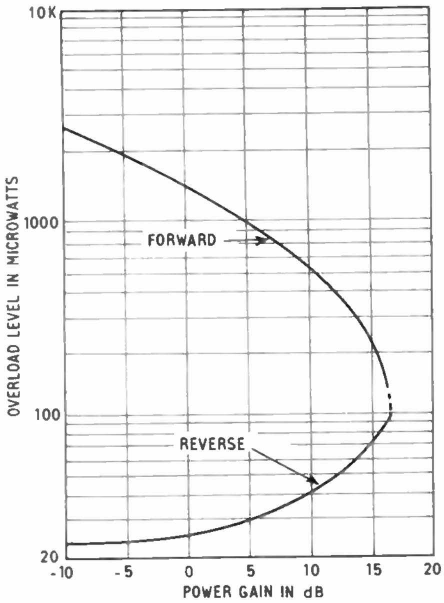
The properties of this type of transistor in comparison with a switching transistor are as follows:

(*a*) Maximum power gain can be realized at a lower consumption operating point and this is usually much greater than the maximum gain of a switching transistor.

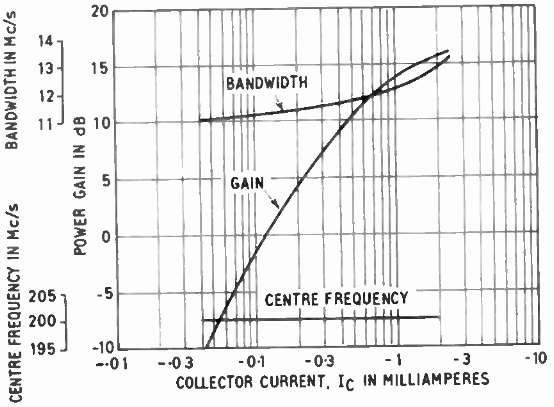
(*b*) Reverse a.g.c. is more effective because of the smaller change in the collector current.

(*c*) The forward a.g.c. requires less drive than in the case of a switching transistor and provides more linear amplification to large signals at low gain levels.

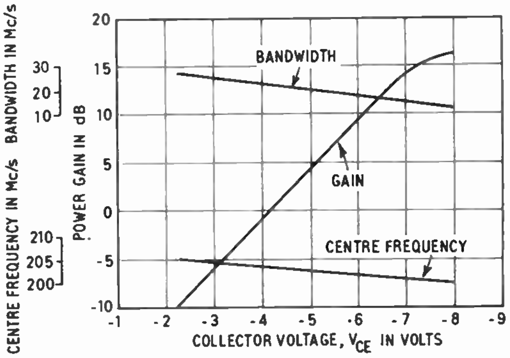
However, this type of transistor should not be used as a large signal amplifier at the normal high gain operating point P_0. As can be seen from Fig. 3, the ridge in the f_T contours will cause non-linear operation to large signals.



(*a*) Overload level vs. power gain for forward and reverse a.g.c.



(*b*) Gain, bandwidth and centre frequency vs. collector current Reverse a.g.c.



(*c*) Gain, bandwidth and centre frequency vs. collector-to-emitter voltage. Forward a.g.c.

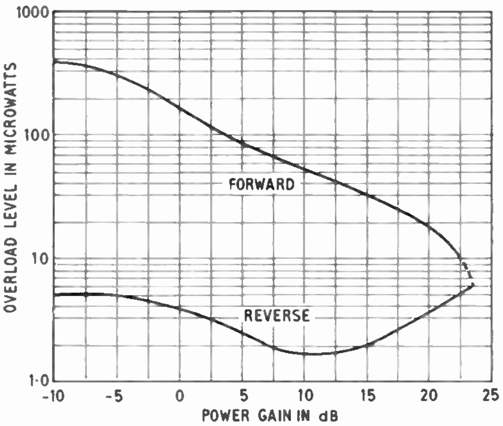
Fig. 4. Typical performance curves for 200 Mc/s r.f. stage using 2N1742.

2. Practical A.G.C. Curves

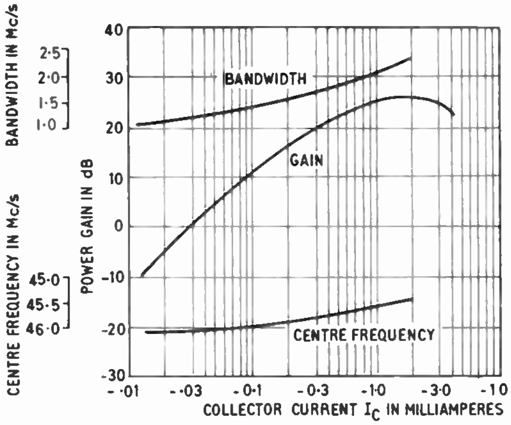
Forward a.g.c. does not lead immediately to modulation distortion, as in the case of reverse a.g.c., and it is in this respect that it is useful. Unfortunately, it requires more control power from the a.g.c. source and has a much greater effect on the bandwidth, than reverse a.g.c.

2.1. *A.G.C. of an R.F. Amplifier*

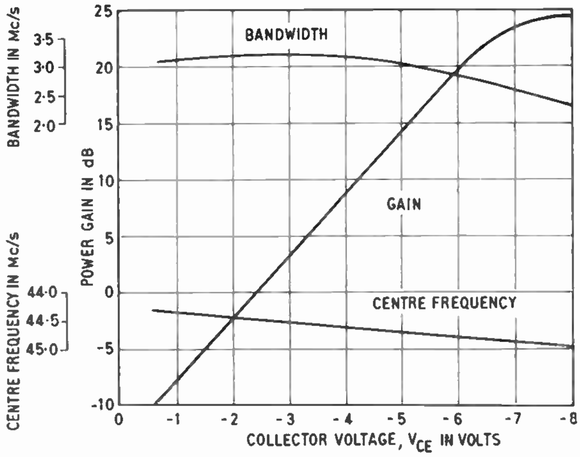
Figures 4 (*a*), (*b*) and (*c*) show performance curves for an r.f. stage operating at 200 Mc/s using the 2N1742. The superior overload performance of forward a.g.c. is shown in Fig. 4 (*a*). The input power in microwatts at which overload occurs is plotted against the stage gain for both forward and reverse a.g.c. With reverse a.g.c. the permissible overload level decreases with stage gain but with forward a.g.c. it increases. Thus, for a reduction of gain of 25 dB, forward a.g.c. provides over a hundred times better overload performance than reverse a.g.c.



(*a*) Overload level vs. power gain for forward and reverse a.g.c.



(*b*) Gain, bandwidth and centre frequency vs. collector current. Reverse a.g.c.



(*c*) Gain, bandwidth and centre frequency vs. collector-to-emitter voltage. Forward a.g.c.

Fig. 5. Typical performance curves for typical 45 Mc/s i.f. stage using 2N1745.

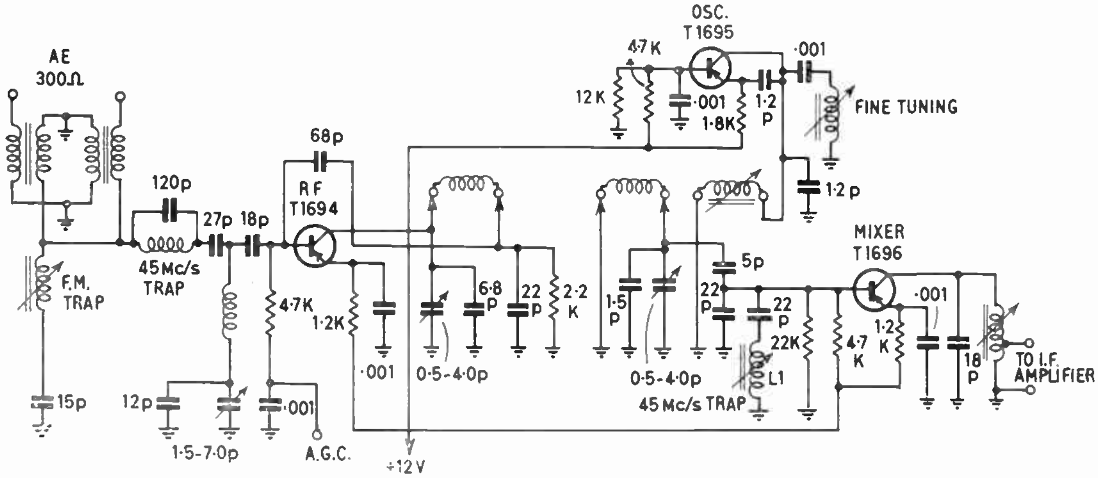


Fig. 6. Television tuner circuit showing application of a.g.c.

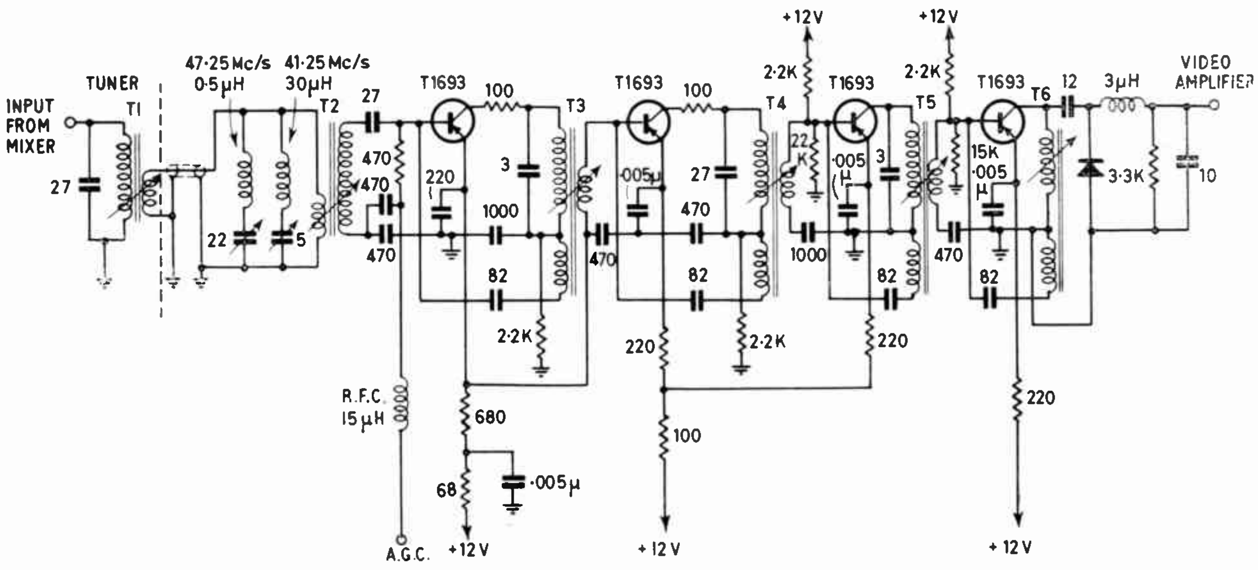


Fig. 7. Four-stage 45 Mc/s television i.f. amplifier showing application of a.g.c.

Figures 4 (*b*) and (*c*) show the effect on bandwidth and centre frequency of reverse and forward a.g.c. respectively. It is seen that forward a.g.c. has a much greater effect on the frequency response.

2.2. *A.G.C. of an I.F. Amplifier*

Figures 5 (*a*), (*b*) and (*c*) show the performance curves for a one-stage i.f. amplifier using the 2N1745 at 45 Mc/s. These curves resemble those for the r.f. amplifier and emphasize the basic properties of forward and reverse a.g.c.

3. Practical A.G.C. Circuits

From the above it follows that forward a.g.c. is likely to be used in the early stages of a receiver. If sufficient forward a.g.c. is applied, the overload of the final i.f. stages can be prevented and cross-modulation throughout the receiver reduced to a minimum.

3.1. *Application of A.G.C. to Tuner*

A circuit of a complete tuner is shown in Fig. 6. The characteristics of the r.f. stage, which has forward a.g.c. are similar to those in Figs. 4 (*a*) and (*c*). Delayed a.g.c. could be applied by selecting a region on the $f_T(V, I)$ curves where the initial movement of the operating point causes only a very small drop in f_T.

3.2. *Application of A.G.C. to an I.F. Strip*

Figure 7 illustrates a method of applying both forward and reverse a.g.c. to a four-stage television i.f. amplifier from a common a.g.c. source. The control voltage becomes increasingly negative as the signal increases. This is applied to the base of the first transistor which, in turn, controls the second transistor by emitter follower action. The third stage is controlled on its emitter. The first and second transistors have therefore forward a.g.c. and the third reverse a.g.c.

4. Acknowledgments

Acknowledgments are due to the Directors of Semiconductors Ltd. for permission to publish the technical information in this article.

5. References

1. W. F. Chow and A. P. Stern, "Automatic gain control of transistor amplifiers", *Proc. Inst. Radio Engrs*, **43**, p. 1119, September 1955.
2. J. R. James and D. J. Bradley, "Transistor frequency response", *Electronic Technology*, **38**, p. 80, March 1961.

Manuscript received by the Institution on 5th June 1961. (Contribution No. 51.)

The other two contributions at this Discussion Meeting have been expanded to full papers. "Transistor Video Amplifier and Line Time-base Synchronization Circuits for Television Receivers" by M. C. Gander and P. L. Mothersole is contained in this issue; "Television Line Time-base Output Stages using Transistors" by K. E. Martin will be published in the July issue.

Collaboration between The Institution of Electrical Engineers and The British Institution of Radio Engineers

Since the Joint Committee of the Institution of Electrical Engineers and the British Institution of Radio Engineers first met in February 1962,† a considerable measure of agreement has been reached on several matters of common interest to the members of both bodies.

In particular, the respective Councils have endorsed the Committee's recommendations on reciprocal arrangements for members to attend Ordinary and Group meetings of both Institutions, and the desirability of arranging joint meetings between the Institutions. Joint meetings have already been held in some of the Local Centres or Sections, and the Councils of both bodies have advised their Local Centres or Sections of the desirability of promoting joint meetings.

The Committees of the Medical Electronics Group of the I.E.E. and the Medical and Biological Electronics Group of the Brit.I.R.E. have been authorized to collaborate in their activities. It is hoped to publish the programme of these joint meetings in the late summer and this may well be followed by joint meetings of other groups of the two Institutions.

Although the representatives of the Brit.I.R.E. felt it would be too late for them to take an active part in the planning of the International Television Conference and its programme, they were nevertheless pleased to lend support by advising their members about the Conference. For their part, the Council of the I.E.E. were able to offer to members of the Brit.I.R.E. the "member rate" registration fee. It is expected that in the organization of future Conferences by either Institution early discussion will take place to determine whether, and if so, at what stage, closer collaboration would be of advantage.

Examination Qualifications. Some agreement has also been reached on the ways in which the two Institutions can collaborate on the basic education of a professional engineer before specialization. The I.E.E. has agreed to ask the Standing Committee for the Joint Part I Examination to invite the Brit.I.R.E. to become associated with the examination. The Joint Part I Examination is already supported by nine other Engineering Institutions in the United Kingdom and the Commonwealth.

General. The Joint Committee recognize that within their terms of reference there is much that can be done and much goodwill has attended their efforts to work in the best interests of the engineering profession as a whole. In particular, the Joint Committee will endeavour to ensure that the part played by the two Institutions in the field of radio and electronic engineering will contribute in the best possible way to the advancement of the science and its applications and development within the industry.

It would not be in the best interest of the further progress of the Committee's work that there should be any conjecture about the way in which the desired collaboration should be developed. Further reports on the work and recommendations of the Joint Committee will of course be circulated to the membership of both Institutions from time to time.

The Medical and Biological Electronics Group of the Brit.I.R.E.

Since the above Group was formed in January 1959 it has co-operated with other bodies in the organization of meetings. Representatives of the Institution have served on the Executive of the International Federation for Medical Electronics and assisted in procuring papers for presentation at the International meetings.

In its three sessions of meetings the Brit.I.R.E. Medical and Biological Electronics Group has held twenty-two meetings. These have served to bring together not only those persons professionally interested in medical electronics, but engineers from outside this field who are able to help with the solution of many problems which exist in the application of electronics to medicine.

As a result of the First International Conference in Paris in 1958, the Institution representative was invited to assist in the formation of a British National Committee. As related in the history of the Institution,‡ subsequent development was disappointing. The present agreement between the I.E.E. and Brit.I.R.E. is particularly welcome since it also opens the way to co-operation with other bodies interested in medical engineering, e.g. The Biological Engineering Society.

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† *J. Brit.I.R.E.*, **23**, page 162, March 1962.

‡ See "A Twentieth Century Professional Institution," page 75.

U.D.C. 621.397.335.2: 621.382.3

Transistor Video Amplifier and Line Time-base Synchronization Circuits for Television Receivers

By

M. C. GANDER†

AND

P. L. MOTHERSOLE

(*Member*)†

Based on a contribution to the Television Group Discussion Meeting on "Transistorized Television Receivers" in London on 6th April 1961.

Summary: The principles of circuit design for transistor video amplifiers for use in television receivers are illustrated by a design using a transistor type AF117 as an emitter-follower driving an AF118 video output stage.

The problems arising from the use of transistors in the synchronizing and line oscillator circuits are discussed. Complete synchronizing pulse separator, flywheel and line-drive circuits are described for both 405- and 625-line receivers. Some alternative circuit techniques are also considered.

1. Introduction

The video amplifier has to provide a large-amplitude wide-band video signal required by the picture tube. In a portable receiver the h.t. potentials required by the video output circuits are obtained from the line time-base and power economy is an essential requirement.

2. C.R.T. Drive Requirements

In the design of a transistor video output stage it is possible to drive the picture tube either on the grid or on the cathode. The reasons for choosing cathode drive are discussed as an introduction to the amplifier design problems.

2.1. *Sensitivity*

The application of the video signal to the cathode of the picture tube enables its maximum effective slope to be utilized. As the video signal modulates the cathode potential, both the grid and first-anode potentials remain substantially unaltered so that the electron current is controlled by the potentials of both electrodes relative to the cathode. With grid modulation, however, the cathode-to-first-anode potential remains unchanged, so there is a smaller change in the beam current.

The relative beam current variations produced by a fixed video drive of 44 volts for both grid and cathode modulation is shown in Fig. 1. For such a comparison the c.r.t. cut-off potentials must be aligned since this corresponds to black level. The peak beam currents are 925 and 1250 μA respectively. Thus cathode drive results in an available beam current increase of some 35% over grid drive for the same c.r.t. operating potentials.

2.2. *Polarity of the Video Signal*

In general, it is desirable in a transistor receiver to have available a signal at low impedance with negative-going synchronizing pulses in order to voltage-drive the synchronizing pulse separator. In a practical video amplifier circuit such a signal may be provided by the emitter-follower stage driving the base of the video output transistor, the collector of which is connected to the picture-tube cathode. This circuit configuration has the further advantage of removing the loading effect of the input impedance of the synchronizing pulse separator from the relatively high impedance of the collector output circuit of the video amplifier.

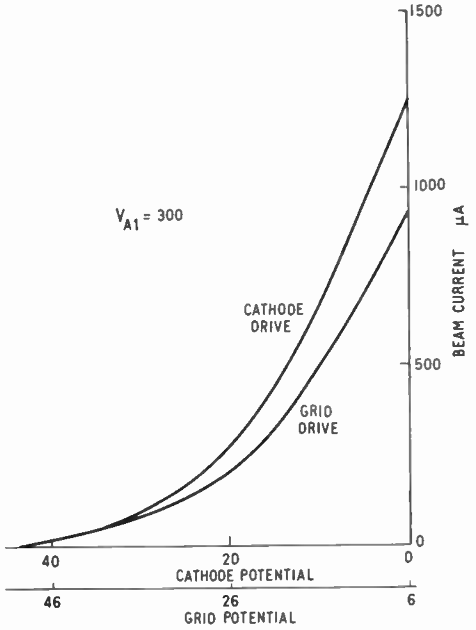

Fig. 1. Typical picture tube drive characteristics (AW 43–88).

2.3. *Noise Pulses*

With positive vision modulation (405-line system) noise pulses often extend above the peak white modulation level.

When grid drive is used together with a *p-n-p* output transistor such noise pulses would over-bottom the output transistor and this results in "pulse stretching" due to hole storage. To minimize this

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effect a limiter diode is necessary to prevent excessive current flowing in the transistor. A similar effect is produced when the contrast control is adjusted so that picture high-lights over-drive the output transistor.

With cathode drive this phenomenon does not occur since large-amplitude noise pulses cut off the output transistor and thus the amplitude of interference pulses is simply limited by the output transistor without significant stretching.

3. Safety of Transistors in the Event of C.R.T. Flashover

Flashover inside a picture tube can generate very high potentials across external circuits, and unless precautions are taken to conduct the energy away from components which are vulnerable to high potentials or currents, device failure may result.

In general, such occurrences are rare and cause no damage to the picture tube itself. In a tube using a unipotential gun the most probable path for a flashover is between the final anode and the focus electrode. A second and less likely path is between the final anode and the first anode.

It has been found experimentally that the waveforms produced by the phenomenon of picture tube flashover exhibit extremely fast rise-times, but the total duration is quite short. However, a consequence of picture tube flashover may be the formation of a long-duration and destructive arc in some other part of the receiver.

The recommended method of protection against flashover damage uses decoupling capacitors connected directly from the first anode and focus electrode socket to the Aquadag coating of the tube. These capacitors should be at least 0·1 μF and have an adequate voltage rating. Because of the fast rise-times associated with the flashover currents it is possible for potential gradients of up to some 100 V/cm to occur in the associated wiring. Thus a short connecting path for the capacitors is essential. These precautions ensure that a potential difference sufficient to produce a further flashover from the grid or cathode to the first anode or focus electrode is not developed.

4. Video Transistor Ratings

In determining the working conditions of the video output transistor it is important to understand completely the transistor ratings so that the device can be fully exploited.

4.1. *Thermal Considerations*

The published data for a video transistor (Mullard AF118) specify the following properties:

Maximum permissible junction temperature = 75°C
Thermal resistance from junction to free air:
(*a*) without heat sink = 0·25 deg C/mW
(*b*) with heat sink = 0·12 deg C/mW.

For a maximum ambient temperature of 45°C the allowable junction temperature rise is 30 deg C. The allowable power dissipation without a heat sink is thus 30/0·25, or 120 mW, and with heat sink is 30/0·12 or 250 mW.

The voltage current relationship for a collector dissipation of 250 mW is shown as a dotted hyperbola in Fig. 2.

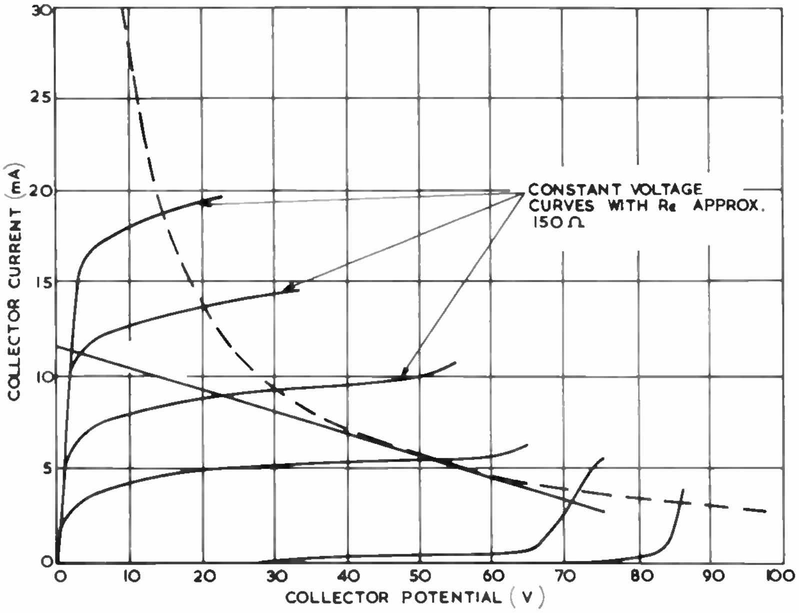


Fig. 2. Transistor characteristics.

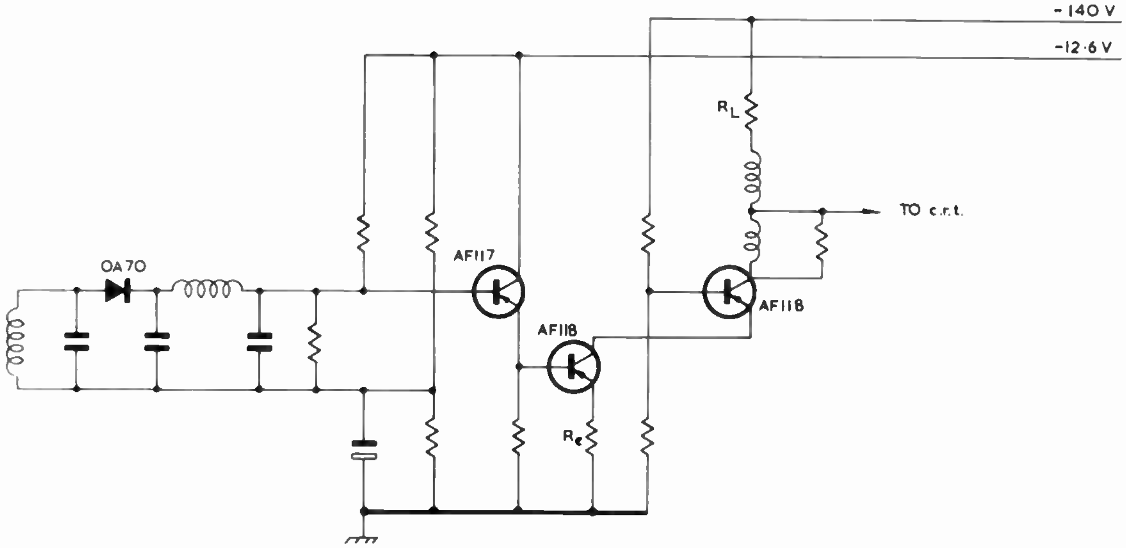


Fig. 3. Video amplifier for 100 V signal swing.

The maximum power dissipation of the transistor will occur at the mid-point of the resistive load line ($P_{\max} = (V_{ht})^2/4RL$, where V_{ht} is the supply potential). In the special case of a television video amplifier the synchronizing pulses will hold the transistor in a hard-on or cut-off condition even when the video signal causes the transistor to operate at its maximum dissipation, that is, approximately a mid-grey picture. In a 405-line system the time occupied by synchronizing pulses is approximately 12%. Furthermore, the transistor will not be at its maximum dissipation during the blanking time. Thus the dynamic operating range can be chosen such that the maximum static dissipation can be safely exceeded by at least 10%.

4.2. *Load Considerations*

In a practical design it is desirable to choose the highest preferred value of load resistor compatible with bandwidth requirements. Hence the maximum value of load for the video amplifier is determined by the shunt capacitance of the circuit.

The synchronizing pulse separator and the a.g.c. system require inputs of a few volts only and will not be attached directly to the high-impedance end of the video load. Thus their capacitive effects on the video output may be ignored.

The only significant capacitive load, therefore, is that of the picture tube and its associated wiring, plus the output capacitance of the transistor. For a capacitive load of about 10 pF a bandwidth of 2·8 Mc/s can be obtained with a 10 kΩ load resistor with series-shunt peaking.

When calculating the maximum transistor dissipation, allowance must be made for the tolerance of the load resistor. If a resistor with a 10% tolerance is used, no derating for this tolerance is necessary in the special case of a video amplifier, because the synchronizing signals reduce the transistor dissipation by about 12%. Since the h.t. for the video amplifier is derived from the line output transformer, the absolute maximum potential must be derated to allow for component tolerances in the line output circuit and for variations in the battery supply potential.

The published data for the AF118 show $V_{cb(\max)}$ to be 50 V. However, in the special case of a television video amplifier, operation in the turnover region is permissible, since the current is limited by the resistive load. The effect of collector turnover is to restrict the amplitude of the output signal. In order to achieve the highest possible turnover potential and useful output, it is necessary to drive the base of the transistor from a low-impedance voltage source, and to employ emitter degeneration.

5. Practical Video Amplifier Circuit Considerations

A major limitation to the attainable frequency response of a wideband amplifier arises from the feedback capacitance. The input impedance of the amplifier becomes very low at high frequencies (Miller effect) and shunts the input circuit. To minimize this effect an emitter-follower is necessary between the video detector and video output transistor.

Several other advantages follow from such a circuit configuration. The major ones are that the low-impedance base circuit for the output stage ensures thermal stability and the high-impedance load on the detector enables optimum efficiency and good linearity to be obtained. Furthermore the synchronizing-pulse separator may conveniently be driven from the low-impedance emitter-follower output.

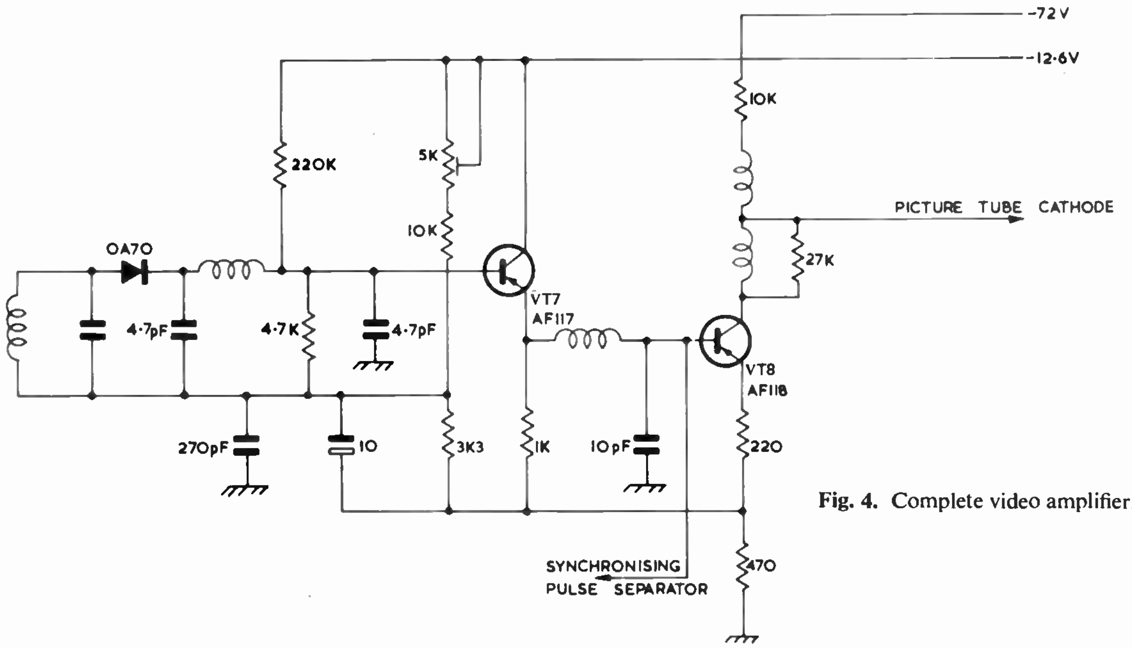


Fig. 4. Complete video amplifier.

When a higher video drive than that provided by a single transistor is required, two output transistors may be connected in series. This arrangement would provide more than adequate drive for a full-performance receiver. The basic circuit of such an arrangement is shown in Fig. 3.

6. Circuit Description

A complete video amplifier designed for use in a portable receiver is shown in Fig. 4.

To drive the picture tube at the cathode requires a negative-going video signal. Since the output transistor produces a phase reversal, the video detector diode is connected to produce a positive-going output. The lower end of the diode load is connected to a potential divider which provides the standing bias for the video amplifier. This bias is arranged to hold the output transistor VT8 in conduction under no-signal conditions and is preset to compensate for component tolerances.

The choice of nominal working point for the output transistor must ensure that variations in the h.t. potential and tolerances in the d.c. supply network do not cause overbottoming of the transistor. Such a condition would lead to hole storage, evident as smearing of the black video information at low settings of the contrast control.

The voltage gain (A) of the output stage is given by

$$A = \frac{R_L}{R_e + r_e} \qquad \ldots\ldots(1)$$

where R_L is the collector load resistance, R_e is the emitter degeneration resistance and r_e is the internal transistor emitter resistance which is approximately equal to $1/g_m$.

As $R_e > r_e$, eqn. (1) may be rewritten

$$A \simeq \frac{R_L}{R_e} \qquad \ldots\ldots(2)$$

The collector load resistor is chosen to have as high a value as possible in the interests of power economy and available output. Since the emitter-follower has approximately a gain of unity, the required value of A is the ratio of the maximum video detector output and the required peak video drive. A typical detector output (V_i) is about 1·5 V and the maximum video output (V_o) is about 65 V.

Thus, from eqn. (2),

$$R_e = R_L \frac{V_i}{V_o}$$

$$= \frac{10 \times 10^3 \times 1{\cdot}5}{65}$$

$$= 230\ \Omega.$$

An r.f. choke is included in the output circuit of the emitter-follower which drives the output transistor directly on the base. The synchronizing-pulse separator may be driven from the emitter-follower output via an a.c. coupling. To increase the drive to the synchronizing-pulse separator above that provided to the output stage, an additional resistor may be included in the shared earth return of the complete video amplifier.

To achieve the optimum overall frequency response series-shunt peaking is employed. The values of the peaking coils were determined empirically with a video sweep generator in conjunction with a sine-squared pulse-and-bar generator (335 μH in parallel with 27 kΩ, and 450 μH).

7. Synchronizing Pulse Separator

The basic techniques involved in the use of transistors are similar to those of the corresponding valve circuits. Transistors eliminate problems associated with hum and microphony but introduce new problems of their own.

7.1. *Circuit Operation*

A transistor which is overdriven so that it conducts only for the duration of the synchronizing pulse tips can provide the basis for the first stage of a synchronizing pulse separator. A circuit using this principle is shown in Fig. 5.

The d.c. component of the video signal is restored at the base of the transistor by the base-emitter diode. The transistor can therefore only conduct during the synchronizing pulses and positive-going separated pulses are produced at the collector.

The minimum amplitude of the video signal input to the separator is determined by the lowest contrast level at which acceptable time-base synchronization is required. The maximum amplitude will occur when the contrast is increased until limiting occurs in the video amplifier, and under this condition the limiting value of reverse base-emitter potential for the separator transistor must not be exceeded.

The first effects on the output waveform of the separator when the video input signal amplitude is reduced are distortion of the field synchronizing pulse and the appearance of video information. After this the amplitude and shape of the line synchronizing pulses will begin to deteriorate.

There are considerable advantages in the use of a two-stage separator circuit particularly when a high degree of noise immunity is required, and such a circuit is shown in Fig. 6. The collector of VT1 is directly coupled to the base of the second separator transistor VT2 so that VT2 is cut off during the tips of the synchronizing pulses while VT1 is conducting. Noise present on the tips of the synchronizing pulses cannot be passed to the output since VT2 is biased beyond cut-off at this level. When the current in VT1 falls, its collector potential rises towards the supply potential. This rise in collector potential is caught by the diode action of the base-emitter junction of VT2. This is illustrated in Fig. 6.

Under extremely low-contrast conditions it is likely that VT1 will not receive a sufficiently large video drive signal to cut off at black level. To prevent feed-through of video information under these conditions, the collector load resistor of VT2 is chosen so that VT2 bottoms when there is only a very small reduction in the collector current of VT1. The suppression of video information does not then depend upon VT1 bottoming.

It can be seen from the video waveform at the base of the first transistor VT1 in Fig. 6 that the most negative boundary of the "slice" is governed by the standing bias on the emitter of VT2. The most positive boundary of the "slice" is governed by the level at which the collector of VT2 bottoms.

The circuit does not require critical component values, but certain principles should be observed in their choice to obtain optimum performance.

The value of the collector load resistor R2 of VT1 determines the base current of VT2, and hence the value of the collector current of VT1 necessary to cause VT2 to be cut off. The base current which flows in VT2 must be large enough to bottom the collector. Therefore the value of R2 must not be made too large. On the other hand, if R2 is too small, the drive requirements of VT1 will be increased, and if the required drive is not available distortion of the separated pulses will occur.

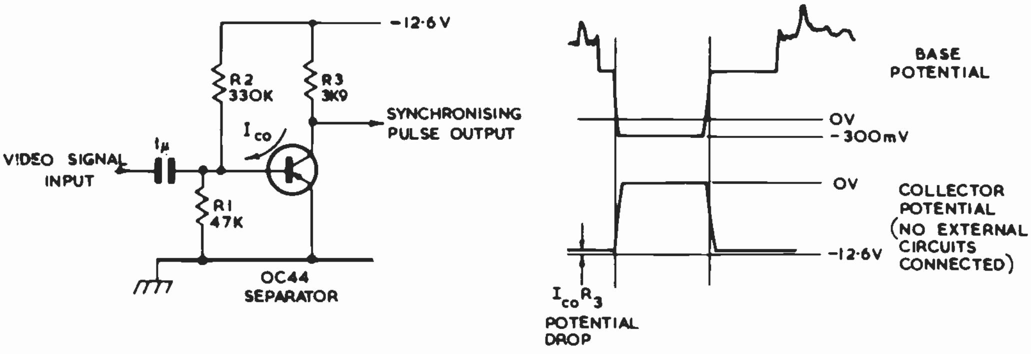
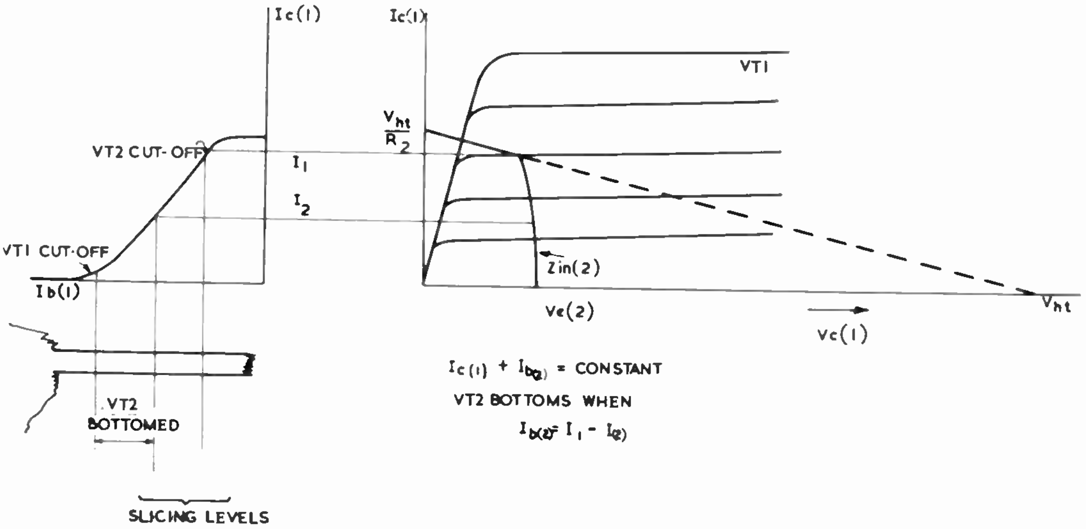


Fig. 5. Single-stage synchronizing pulse separator.



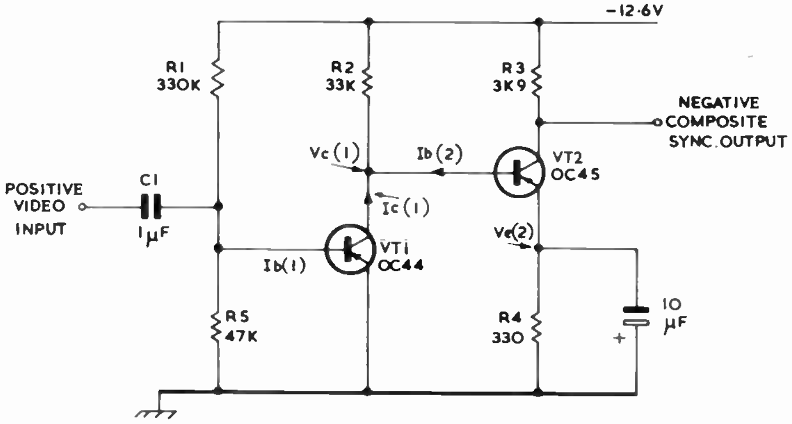


Fig. 6. Two-stage synchronizing pulse separator.

7.2. *Line Time-base Synchronization*

When a transistor is suddenly cut off a time delay exists between the application of the switching waveform and the cessation of collector current. Because of this the operation of transistors in power-switching circuits differs from that of valves. Thus, if the line time-base is directly synchronized, a time delay (about 3 μs) will occur between the synchronizing pulse edge and the start of the flyback. The effect of this delay is further aggravated by the use of a long flyback time. The result is a considerable shift of the picture and, to overcome this, flywheel synchronization with a suitable phase-shift network incorporated into the feedback loop must be used.

7.3. *Transistor Cut-off Frequency and Current Gain*

The shape of the separated synchronizing pulses is largely determined by the base circuit impedance and the transistor cut-off frequency. The use of a transistor with an inadequate cut-off frequency results in deterioration of the pulse edges, and this is particularly noticeable with small signal inputs. For a given circuit, therefore, the transistor cut-off frequency must be high enough to ensure a satisfactory output waveform slope over the range of input signal level used. Experiments carried out in a complete receiver indicate that a minimum value of f_1 of about 2 Mc/s is required.

The minimum input signal amplitude which will bottom a collector in a given circuit depends on the value of $\bar{\alpha}'$ of the transistor. A type with a sufficiently high minimum value is therefore required.

7.4. *Field Pulse Separation*

The separation of the field synchronizing pulse from the composite waveform can be accomplished with any conventional circuit, since no special problems are introduced by the use of transistors.

7.5. *Leakage Currents in the Separator Transistor*

The leakage current I_{co} of the base-collector diode flows in the collector load impedance whether the transistor is conducting or not. When the transistor is conducting an additional leakage current which can approach the value $\alpha' I_{co}$ will flow in the collector circuit, but since the collector will be bottomed during the synchronizing pulse tips, this current is unimportant. The value of I_{co} is approximately doubled for each 8 deg C rise in junction temperature. As the value of I_{co} increases, the d.c. potential across the collector load increases and so reduces the effective supply potential, with a consequent reduction in the output waveform amplitude. A transistor type with a low value of I_{co}, such as a small junction transistor, is necessary.

8. Line Flywheel Circuits

8.1. *Requirements*

For the 405-line system a pull-in range of about 600 c/s (± 300 c/s) has proved in valve receivers to be a reasonable compromise between noise immunity and a good pull-in range. With such a pull-in range, short-term line oscillator frequency drift should not be greater than about ±200 c/s if a margin of ± 100 c/s is to be allowed for changes in the transmitted line synchronizing pulse frequency. Short-term drift of the line oscillator frequency commonly results from variations in supply potentials in the receiver and (with transistors) changes in ambient temperature. Frequency drift due to these causes can also occur in other parts of the circuit within the flywheel feedback loop, so that, although a stable line oscillator is the basis of a satisfactory flywheel system, the overall stability of the system is of final importance.

8.2. *Sequence of Stages*

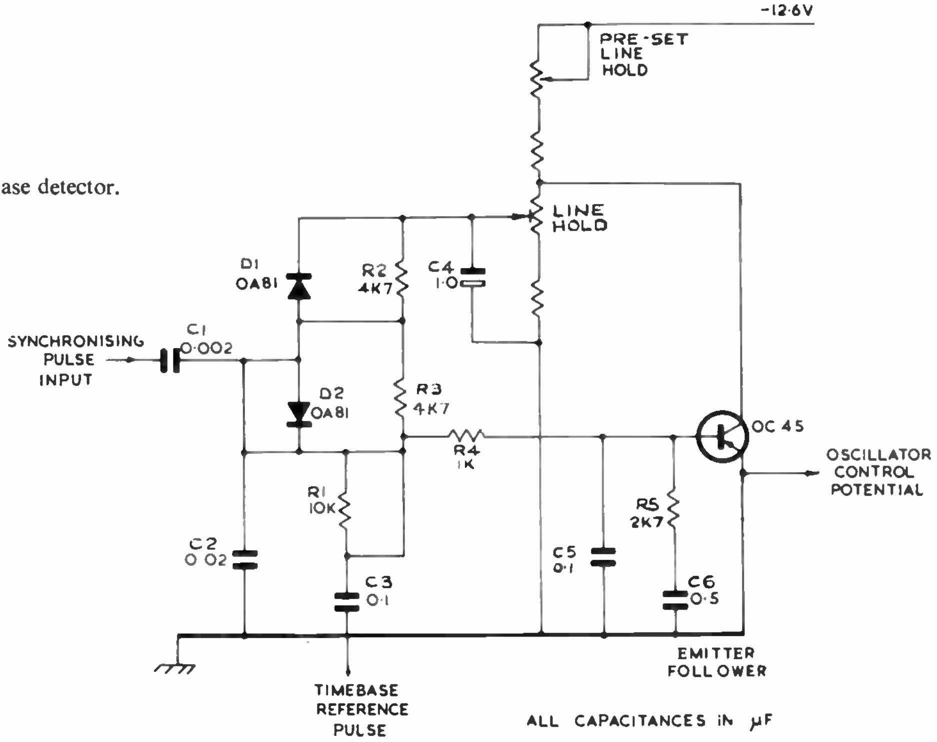
The circuits between the phase detector and the line output stage of a flywheel system must provide power amplification. The power available in the form of the d.c. control potential from the phase detector is limited by the impedance level of the reference and gating waveforms available in the receiver. The required power gain can be achieved by several methods.

The line oscillator can immediately follow the phase detector, in which case a low-power oscillator must be used because of the limited power available from the phase detector. However, two stages of a.c. amplification following the oscillator would probably be necessary, although in some circumstances sufficient power gain may be obtainable with only one stage.

A second method is to connect an emitter-follower d.c. amplifier after the phase detector. The emitter-follower provides the control for the line oscillator which may operate at an intermediate power level, with one stage of a.c. amplification supplying the drive to the line output transistor.

A third method in which the line output stage is driven directly from a high-power line oscillator controlled by a relatively high gain d.c. amplifier is feasible. A high value of d.c. gain in the system is very undesirable, however, since it would make the circuit susceptible to supply potential variations.

Fig. 7. Double-diode phase detector.



In general, therefore, a.c. amplification is to be preferred since it is free from d.c. drift and temperature problems.

Any transistor oscillator will, however, require power to control its frequency, and some form of buffer is necessary between the oscillator and the output stage. A practical flywheel system therefore consists of a phase detector and emitter-follower controlling an oscillator with a buffer amplifier driving the output transistor.

9. Phase Detector

A low d.c. output impedance is required for the phase detector. Diode circuits have a relatively high output impedance and an emitter-follower is therefore necessary. A phase detector has two basic modes of operation. Either the synchronizing pulses are used as gate pulses with the time-base pulse as a reference, or the time-base provides the gate pulses with the synchronizing pulse as a reference.

The pulses produced by the output transformer in a transistor receiver are not suitable for use as gate pulses directly, since slow flyback and third harmonic tuning are used. These techniques result in long flyback pulses and hence long gate pulses compared with the reference synchronizing pulse. The alternative and preferred technique is to use the synchronizing pulses for gating, with an integrated flyback pulse for reference.

A simple double-diode phase detector circuit that only requires a single gating pulse is more economical than the conventional bridge circuit. Such a circuit is shown in Fig. 7. In this type of circuit, even when an emitter-follower is used, it is still necessary in the interests of d.c. stability to use resistors with values which are as low as possible.

Since the collector-junction leakage current (I_{co}) in the emitter-follower transistor flows into the phase detector its value must be kept small to avoid excessive frequency drifts with temperature. This can be achieved by choosing a suitable transistor type and operating conditions so that its I_{co} is minimized. An OC45, if operated with V_{cb} not greater than 2 V will have an I_{co} not greater than 2 μA at 25°C. Its collector is therefore fed from a tap in the potential divider chain.

An economical phase detector circuit that uses a transistor is shown in Fig. 8. The line synchronizing pulses are differentiated by the current-fed transformer T1. Differentiated synchronizing pulses are applied to the base of an emitter-follower phase detector VT2 at a d.c. level determined by the setting of the line-hold control RV1. A parabolic reference waveform derived from the line output stage is fed to the emitter of VT2 which thus conducts during the narrow positive tips of the parabola; the emitter current which flows and hence the d.c. output, depends upon the phase relationship between the differentiated synchronizing pulses and the parabolic waveform. The d.c. output controls the frequency of the blocking oscillator by varying the base potential. A CR low-pass filter is used in the emitter circuit of the phase detector transistor. A comparatively large collector leakage current can be tolerated in this transistor because of the pulsed operation, and because of the low impedance in the base circuit.

A disadvantage of this type of circuit is that the d.c. output from the phase detector, and hence the oscilla-

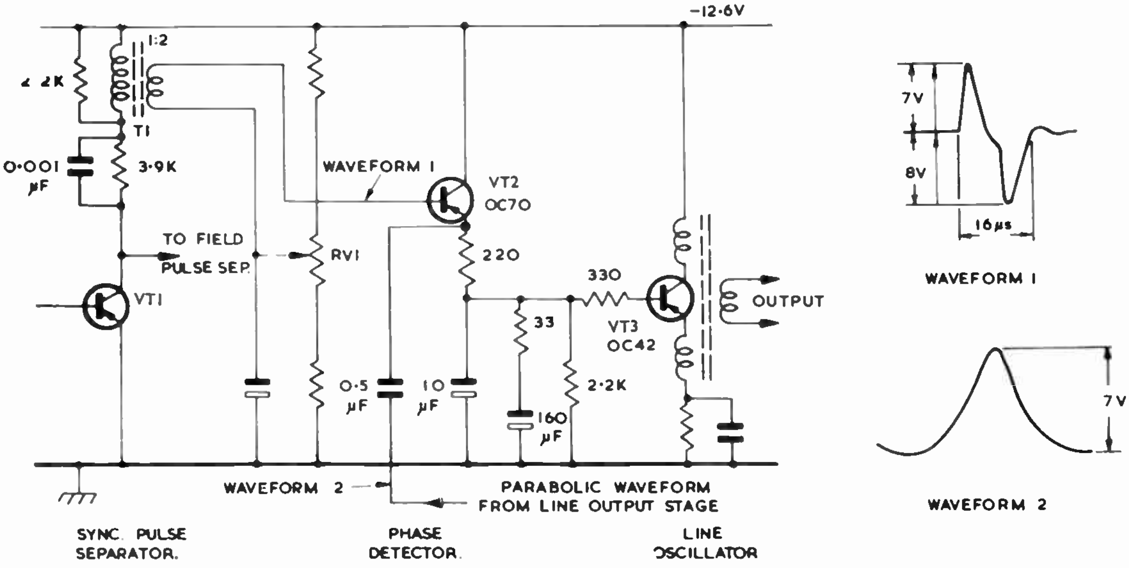


Fig. 8. Transistor phase detector.

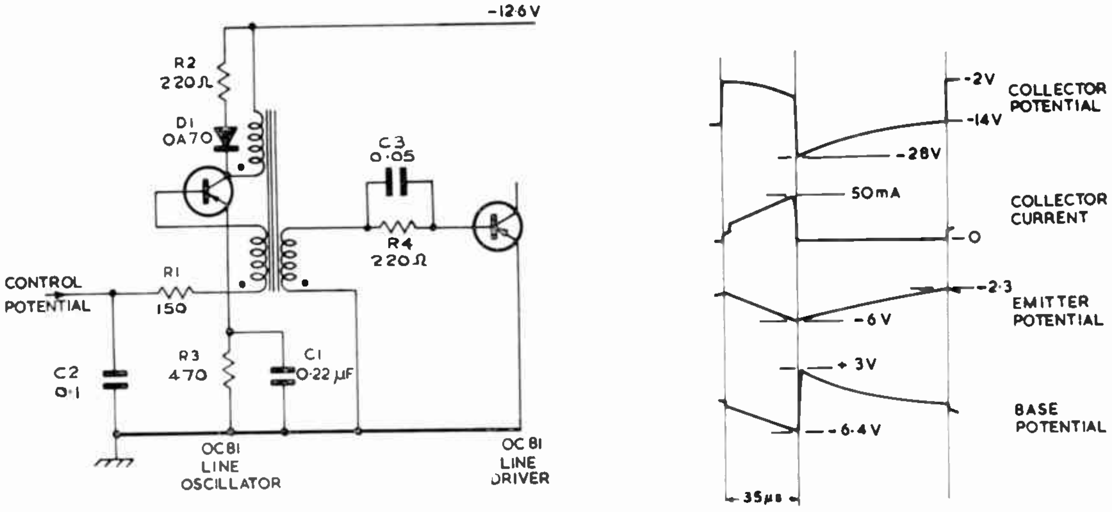


Fig. 9. Line blocking oscillator.

tor free-running frequency, changes between signal and no-signal conditions. The source of control is such that, with no input signals, the oscillator frequency decreases, and this increases the peak potentials in the line output circuit. Furthermore, the catching range is not symmetrical about the no-signal oscillator frequency.

10. Line Oscillator

The oscillator must provide power for the following stage, and for maximum power transfer a coupling transformer is necessary. The use of an additional winding on the transformer enables a blocking oscillator to be formed with the minimum of components. Further advantages of the blocking oscillator are the low output impedance and steep waveform edges.

10.1. *Circuit Description*

The circuit for the line blocking oscillator together with the operating waveforms is given in Fig. 9. The circuit is that of a grounded-emitter oscillator with feedback from the collector to the base circuit, and emitter timing. The frequency is controlled by variation of the base-circuit potential.

The width of the current pulse produced is 30 μs and this depends mainly on the transformer primary inductance, the series resistance of the base, emitter and collector circuits, and the value of C1. Because of the effect of series base-circuit resistance on the pulse-width, the resistance R1 is included to swamp out the variation of $r_{bb'}$ from one transistor to another. The capacitor C2 by-passes the a.c. component of the base circuit current to earth and its value has no significant effect upon the circuit action.

When the transistor switches off, the energy built up in the transformer during the current pulse causes a large negative pulse potential to occur at the collector, with consequent pulses in the base and output windings of the transformer. To reduce the amplitude of this pulse, the diode D1 and the resistor R2 are connected across the transformer collector winding so that the pulse energy is dissipated in R2.

10.2. *Effects of Temperature and Supply Potential Variation*

With the timing network in the emitter circuit, the capacitor C1 discharges through R3 and the base-emitter junction biased in reverse. The emitter-junction leakage current (I_{eo}) therefore assists in the discharge of the capacitor but since the value of R3 is small compared to the leakage-path resistance the effect of variation of I_{eo} upon oscillator frequency is small.

Since I_{eo} flows in the base circuit of the oscillator, the source resistance of the network which supplies the base circuit potential must be sufficiently low to ensure that variations in I_{co} will not cause a significant change in oscillator frequency. Other transistor parameters which change with temperature are V_{be} (approximately -2 mV/deg C) and α' (approximately $+1\%$ per deg C) and these contribute to the total drift in the oscillator.

10.3. *Transistor Requirements*

Because of the large amount of positive feedback and the independence of circuit operation from transistor parameters, the transistor requirements for the blocking oscillator are not stringent. However, as peak pulse potentials and currents can be fairly large in any blocking oscillator, due allowance must be made for them in selecting the transistor type.

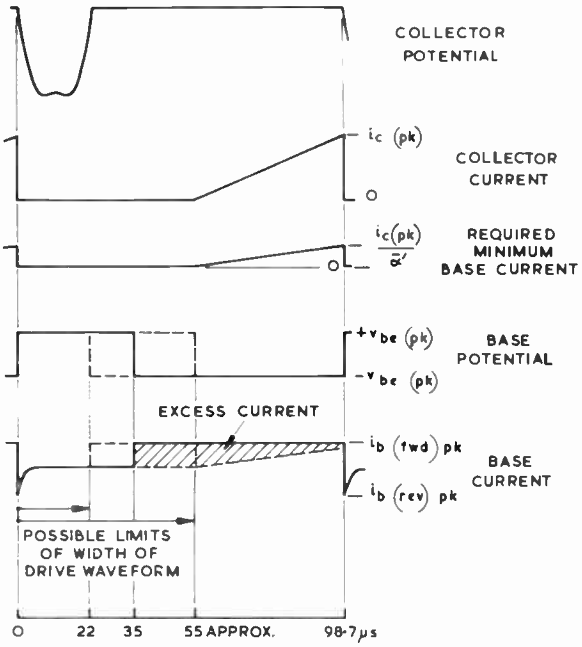


Fig. 10. Idealized waveforms for line output stage.

11. Line Driver Stage

The driver stage must supply a waveform of low source impedance to be base of the line output transistor which maintains suitable drive conditions despite line oscillator frequency variations and changes in supply potential. Furthermore, sufficient current must be available to bottom a line output transistor having a lower-limit value of $\bar{\alpha}'$.

11.1. *Drive Waveform Requirements*

To initiate the flyback the drive waveform must cut-off the line output transistor as rapidly as possible and hold it cut-off for the duration of the flyback pulse. In Fig. 10 the idealized circuit waveforms are shown.

After the flyback pulse a further period of cut-off may elapse while the energy-recovery diode is conducting. Before the energy-recovery diode cuts off, the output transistor is driven into conduction, so that collector current may start to flow as soon as required. The base input current must be sufficiently large to support the collector current required for bottoming until the end of the scanning period. The latter requirement is very important because, if the collector is allowed to emerge from bottoming during its conduction period, a large increase in collector power dissipation occurs, which may cause failure of the line output transistor.

To achieve the highest possible efficiency in the driver stage, the transistor must act as a switch in conjunction with a driver transformer. This method of operation produces a rectangular drive waveform. The base current required by the output transistor at the end of scan is determined by the peak collector current and $\bar{\alpha}'$.

When the output transistor is rapidly cut off at the end of scan, a large pulse of base current flows because of the sudden removal of the base charge. The drive circuit must be capable of supplying this current spike to ensure that the collector current is cut off rapidly. In a practical circuit, when the h.t. potential is at its maximum value, this current spike should not exceed the output transistor rating.

11.2. *Practical Driver Circuit*

A typical driver circuit is shown in Fig. 11. A winding on the line oscillator transformer supplies the switching waveform to the base of the driver transistor. This waveform causes it to conduct for about 30 μs, the driver transistor acting as a switch. When the transistor conducts, the collector current, after an initial step due to the load of the transformer secondary, rises linearly as energy is stored in the collector-winding shunt inductance. When the transistor is cut off, this energy must be discharged and it is transferred into the base circuit of the line output transistor as drive current. This method, whereby the driver stage is conducting while the output transistor is cut off, is therefore inherently efficient because the discharge of the stored energy adds to the output current of the driver transformer.

The alternative method of operation is with the driver transistor conducting during the conduction periods of the line output transistor. In this case, the discharge of the energy in the driver transformer occurs during the time when the output transistor is cut off. Because of the low damping, a large-amplitude pulse is produced and a series damping diode and resistor network are necessary to dissipate the stored energy. As experiments with both techniques show the latter to consume some 30% more current than the former for the same drive output, it will not be considered further.

When the driver transistor is cut off its collector potential goes more negative than the supply potential. This is due to the necessary condition that the mean potential across the collector-winding shunt inductance must be zero. The amplitude of the waveform produced across the collector winding is therefore determined by the supply potential and the duty ratio of the driver stage. In a typical circuit with a supply potential of 12 volts, the collector waveform amplitude is about 16 V peak-to-peak. A transformer ratio must be chosen to provide the drive required by the line output transistor and this is typically about 4 volts.

The internal resistance of the driver stage, looking back into the transformer secondary is typically about

0·3 Ω and this, together with an external resistor, R2, should give a drive current which is inside the desired limits despite spreads in the line output transistor.

The driver transformer primary inductance will determine the peak current in the driver transistor and the amount of sag on the drive current waveform. For these reasons the primary inductance should be as large as possible consistent with size, winding resistance and leakage inductance. A low value of leakage inductance is required to obtain a sufficiently fast current pulse from the secondary winding at the instant when the line output transistor is being cut off. To achieve this the transformer primary winding is wound in two sections with the secondary winding sandwiched between them.

12. A Complete Oscillator and Flywheel System (405 Line)

The complete circuit of a phase detector, line oscillator and buffer amplifier is shown in Fig. 12.

To obtain good frequency stability the phase detector has a low output resistance so that I_{co} flowing in the emitter-follower transistor does not appreciably affect its output potential. The collector of the emitter-follower is fed from a low potential so that V_{cb} is not greater than -2 V. The frequency stability of the complete flywheel circuit is such that an increase of temperature from 20°C to 50°C results in a frequency drift of only 140 c/s.

The catching range of the flywheel is determined by the filter network between the phase detector and the oscillator. The filter component values have been chosen to give a catching range of about ±350 c/s. The holding range of the system is greater than 1 kc/s.

To accommodate the variations in line oscillator frequency that can occur from component spreads, a wide range of frequency adjustment must be provided. However, it is desirable to restrict the customer-operated frequency control to about 1 kc/s, and therefore two controls (one factory pre-set) are provided which give a total control range of about 3 kc/s.

13. Sinewave-Stabilized Blocking Oscillator

A method of reducing the current flowing in the oscillator base circuit is to connect a parallel resonant LC network as shown in Fig. 13. This presents a high series a.c. impedance which reduces the mean value of the base current. The reduction of base current reduces the load on the phase detector and may enable the emitter-follower to be omitted. No deterioration of oscillator waveform edges occurs because the resultant sinusoidal component of base potential gives very rapid switching of the transistor. An additional benefit, which is to be expected, is a substantial increase in oscillator frequency stability.

Unfortunately, such an arrangement reduces the sensitivity to control by some 5–10 times and unless the phase detector can provide a correspondingly larger output potential the pull-in range and phase characteristic will be inadequate.

For a 405-line flywheel system a pull-in range of about ±350 c/s is required (7% variation) and it does not seem to be practicable to realize this is a satisfactory way without the emitter follower.

However, for a 625-line flywheel system (crystal-locked) a pull-in range of about ±200 c/s (2·6% variation) is consistent with good noise immunity. With the lower percentage variation required here it

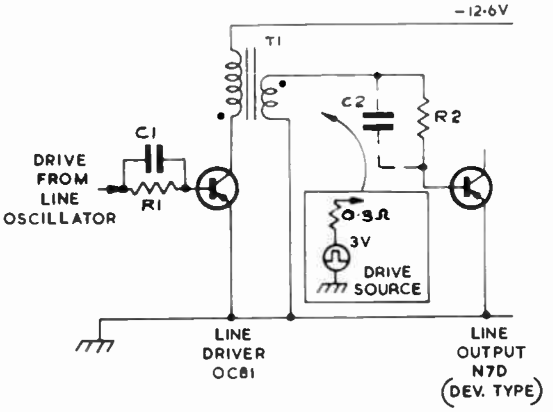
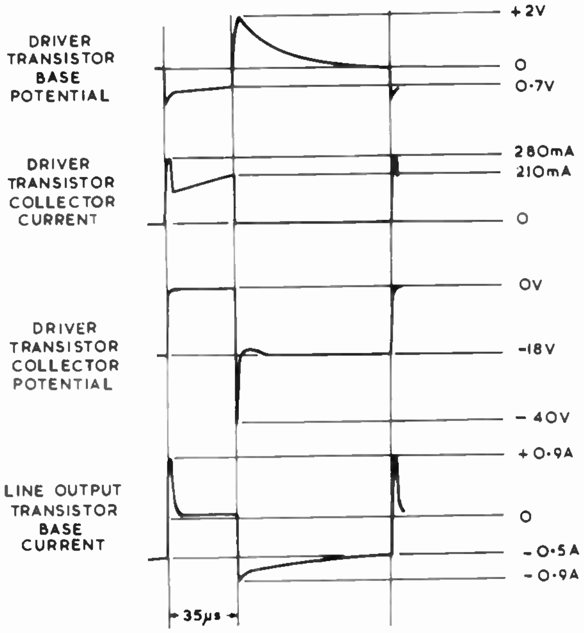


Fig. 11. Line driver stage.



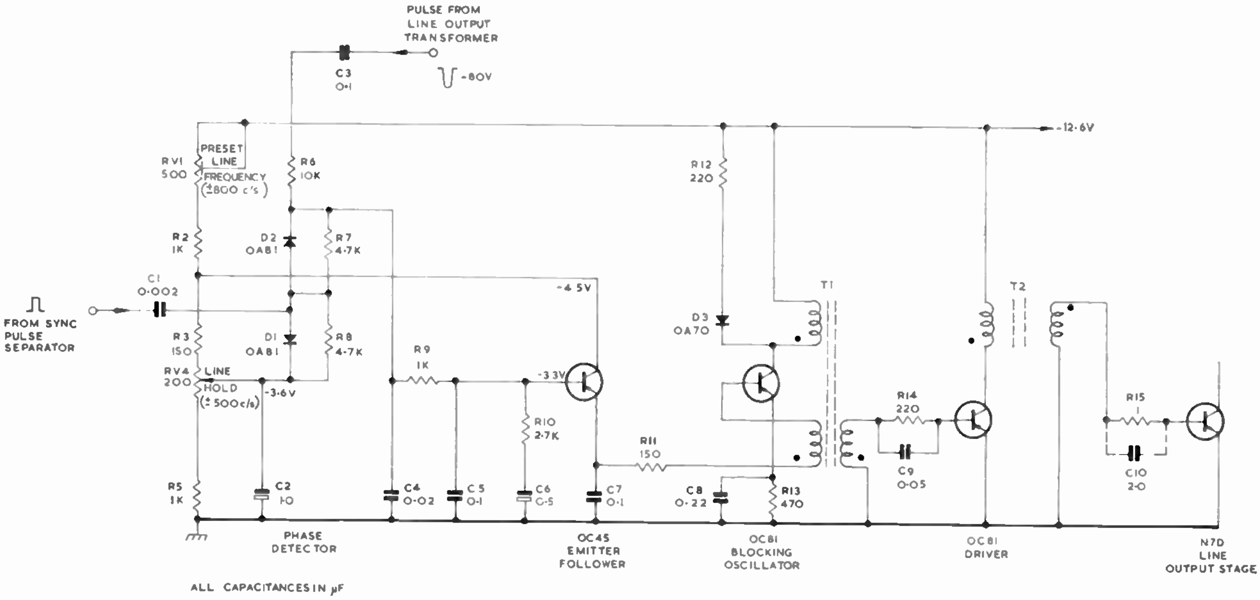


Fig. 12. Complete flywheel circuit (405 lines).

is possible to obtain a satisfactory performance without an emitter-follower stage.

14. Complete Oscillator and Flywheel System (625 Line)

The complete circuit of a phase detector, line oscillator and buffer amplifier is shown in Fig. 13.

The phase detector is similar to the one previously described but a larger-amplitude reference pulse (+400 V) is required to obtain sufficient output to control the oscillator. Inductance L1 is adjusted to set the oscillator frequency to 15·625 kc/s and RV1 provides a user-operated line-hold control.

A temperature-dependent resistance (R4) is included in the phase detector circuit to compensate for changes in the oscillator transistor characteristics with temperature. The oscillator frequency drift remains within ±50 c/s when the temperature is increased from 20°C to 50°C.

The frequency shift with change of supply potential is about 100 c/s per volt.

15. Sinewave-Controlled Blocking Oscillator

When a very high order of noise immunity is required, it will entail a reduction of the flywheel catching range to the order of 50 c/s. The oscillator

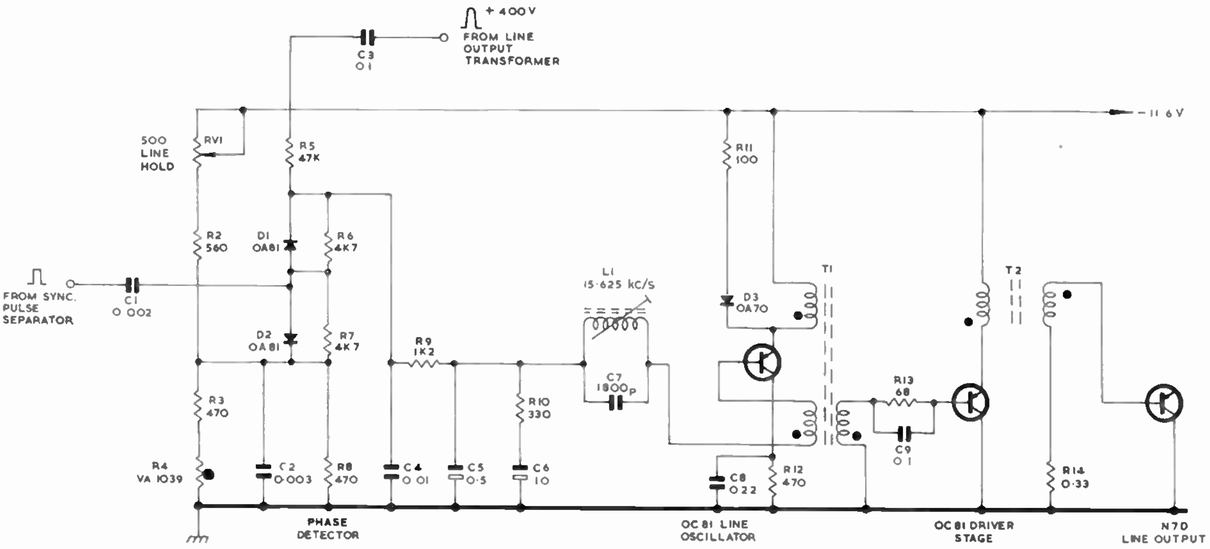


Fig. 13. Complete flywheel circuit (625 lines).

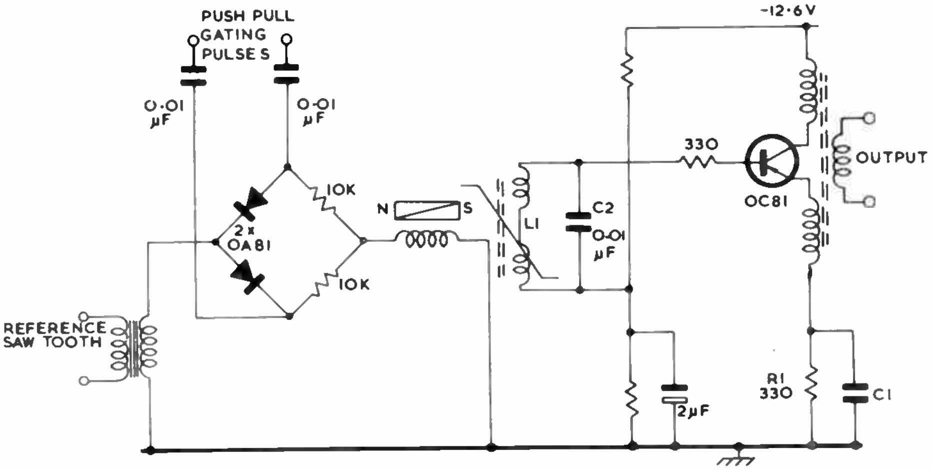


Fig. 14. Blocking oscillator with LC frequency control.

stability must then be improved, and it becomes essential to use a resonant circuit to determine the oscillator frequency. As the oscillator becomes increasingly independent of external influences it is inherently difficult to control the frequency of oscillation simply by varying the oscillator potentials. The most logical method, therefore, is the control of one of the reactances of the tuned circuit. This is most readily accomplished by use of a reactance transistor or saturated reactor.

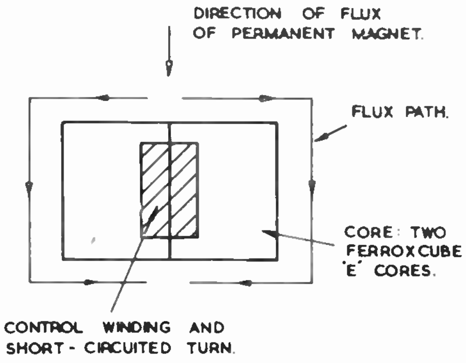
In their basic form, both these systems shunt the tuned circuit with a reactance which is proportional to the h.t. potential, and they therefore provide unacceptable frequency stability. With the saturated reactor, however, this disadvantage can be readily overcome by employing a permanent magnet to bias the core so that no standing current is required in the control winding. Flux linkage between the magnet and the core can be varied by orientation of the magnet or by magnetic shunting, and this provides a convenient form of line-hold control to set-up the initial oscillator frequency.

In principle, the saturated-reactor technique may be applied to any type of line oscillator in which the frequency is controlled by an LC resonant circuit. By way of an example, a blocking oscillator is shown in Fig. 14. Here the normal exponential timing waveform developed across C1R1 is augmented by a sinusoidal waveform obtained by base current shock-excitation of the resonant circuit L1C2. Thus the blocking oscillator frequency is predominantly determined by the components L1C2 and is therefore substantially independent of the h.t. potential. The phase detector shown is the familiar balanced double-diode type designed to provide a reasonably low output impedance. The reactor control winding can be connected directly to the phase detector, thus dispensing with any form of d.c. amplifier and its associated problems of drift and dependence on h.t. potential.

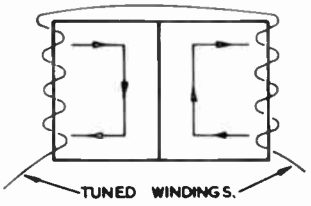
The reactor is constructed with two standard Ferroxcube "E" cores (Mullard type No. FX1238) in such a manner that there is no flux linkage between the tuned circuit and the control winding, and the control winding itself can consist of a large number of turns to give high sensitivity (Fig. 15).

15.1. *Performance*

The maximum sensitivity which can readily be obtained with this circuit is typically a change of ± 1 kc/s oscillator frequency for ± 100 μA change in control current. This relates to a control winding



(*a*) Control winding and permanent magnet.



(*b*) Tuned windings.

Fig. 15. Saturated reactor flux paths.

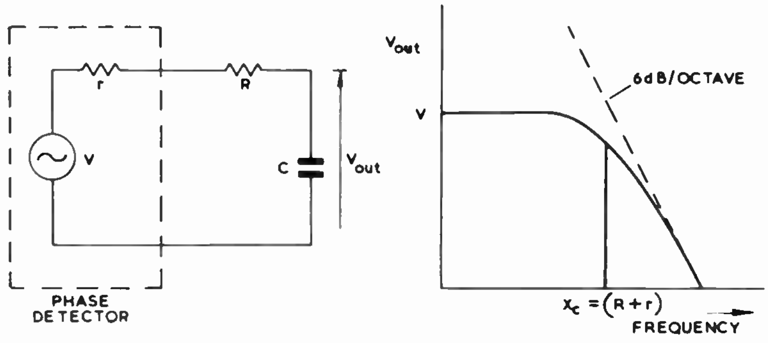
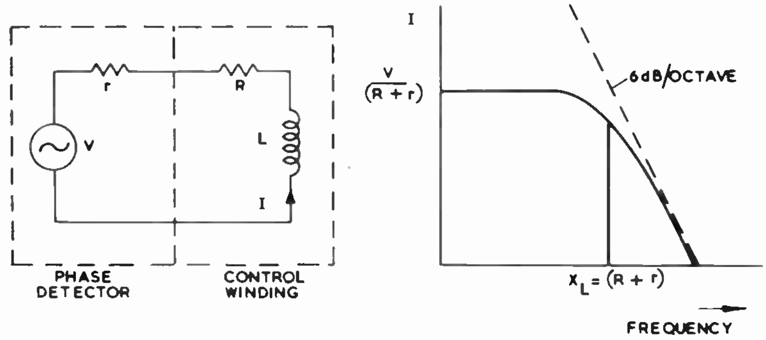


Fig. 16.

(*a*) CR filter used in conventional flywheel line oscillator; frequency ∝ V_{out}.



(*b*) Saturated-reactor filter line oscillator; frequency ∝ *I*.

resistance of approximately 20 kΩ. With a control winding of these dimensions, the inductance is considerable, and thus the cut-off frequency is rather low. To increase the cut-off frequency, it is necessary either to increase the output resistance of the phase detector or to decrease the impedance of the control winding. Both these measures degrade the matching between the phase detector and the control winding. For this reason the maximum catching range obtainable with this type of circuit is limited to the order of ± 150 c/s.

No RC network is required to provide the necessary lowpass filter because the control winding is inherently inductive, and therefore the current which flows in this winding is inversely proportional to frequency. It is the current flowing in the control winding which determines the oscillator frequency. These points are illustrated in Fig. 16.

The frequency/control current characteristic of this circuit shows a hysteresis effect associated with the hysteresis curve of the core material. The effective frequency stability therefore depends on the core material used and on the extent to which it is biased.

16. Conclusions

The complete video amplifier for a television receiver requires at least two transistors (emitter-follower plus the output stage). Thus this stage will be more expensive than its valve counterpart which requires a single valve (in practice half of a double valve).

The turn-off delay of the line output transistor, aggravated by the use of a long flyback time to ease the output transistor requirements, necessitates the line oscillator triggering before the leading edge of the synchronizing pulse. The use of flywheel synchronization is therefore necessary to provide the required phase shift or time correction in the line synchronization circuit. Furthermore the complete line driver circuit requires at least a buffer stage extra compared with a valve receiver.

The use of transistors in these television circuits at the moment therefore cannot be justified on the score of cost or performance. The main application is likely to be, therefore, where the low power requirements of transistors and their small size make their use essential. For entertainment applications this is likely to be in the portable receiver.

17. Acknowledgments

The authors would like to acknowledge the contributions made to the work described in this paper by their colleagues, in particular Messrs. D. R. Birt and D. G. Thompson. They also wish to thank the Director of the Mullard Research Laboratories and the Directors of Mullard Ltd. for permission to publish this paper.

Manuscript first received by the Institution on 6th October 1961 and in final form on 24th January 1962 (Paper No. 732).

News from the Sections . . .

Southern Section

On 13th February, the Section were the guests of the Electronics and Control Group of the Southern Section of the Institution of Electrical Engineers at a discussion on "What Should be Taught—a Review of the Training of Electronic Engineers". Dr. G. B. B. Chaplin, Chairman of the I.E.E. Group, opened the meeting at the University of Southampton and invited Dr. W. A. Gambling, Chairman of the Brit.I.R.E. Southern Section to take the Chair.

Dr. Gambling said that the discussion would explore the content of courses leading to professional status in radio and electronic engineering. He believed that if we were to include everything we thought desirable in such a course, the problem of what to leave out had then to be solved. Training should develop an inquiring mind, and should encourage the application of commonsense to a particular problem. Training should also be aimed not merely at the present but at the probable future problems the engineer is likely to be faced with. There might even be a case for scrapping existing engineering courses and starting again from scratch, perhaps with more of a bias towards physics and mathematics. The views of Industry, the eventual employer, would be especially welcome here.

The first speaker was Professor E. E. Zepler, Professor of Electronics at the University of Southampton (Immediate Past President of the Brit.I.R.E.) who took the view that one of the main objects of the University course was to teach the student to think for himself, use commonsense and exercise critical judgement. Courses should not be too subservient to the needs of Industry, but should lay stress on fundamentals especially in mathematics and physics for those studying light current subjects. Deep specialization in a few subjects he considered to be more important than a wide field covered in a superficial manner. The importance of laboratory work was emphasized and he was in favour of students undertaking specific projects in their later terms. Examinations were a necessary evil but here the questions should be set in such a way as to exercise the thinking ability of the student rather than to lay emphasis on pure memory.

The second speaker, Mr. P. Cook, was from industry and said that though he was in general agreement with Professor Zepler he thought that since the engineer ultimately had to control staff, management studies should form part of the University courses. Dealing with the content of the courses, he could see little advantage in the light-current student having to spend so much time on the detailed study of such unrelated subjects as 3-phase systems, symmetrical components and vector analysis.

Mr. H. S. Stachera (Southampton University) thought that it was better for degree courses to be lengthened rather than for subjects to be left out. A more practical solution would be to extend the course to four years plus a diploma year.

This view was supported by Professor L. G. A. Sims (also of Southampton University) who suggested that personality was high among desirable attributes which a student should acquire, hence the University course should encourage the art of speaking in public.

Many other opinions and suggestions were put forward and, summing up, Dr. Gambling said that although there had been much useful and constructive criticism he would have liked more contributions from industry. The main points arising from the discussion had been that degree courses could, with advantage, be lengthened. This would solve the problem of reconciling training in breadth with that of depth. It was imperative to have a good grounding in the fundamentals of one's subject, and deeper thinking should be encouraged.

Some criticisms of lecturing staff were well founded, and the points made regarding industrial experience, tuition by lecturers currently carrying out research in their field and the need to inculcate enthusiasm into the student, were very relevant.

Communication between lecturer and student could be improved. There should also be closer liaison between University departments with a view to standardizing techniques and symbols in allied subjects such as physics, mathematics, electronics and electrical engineering.

J. M. P.

Scottish Section

The Edinburgh and Glasgow meetings of the Scottish Section on 7th and 8th March heard a paper by Mr. J. L. Somerville of the Post Office Engineering Department, on "Carrier Telephony". Unfortunately, illness prevented the author from attending personally and his paper was presented at short notice by two colleagues, Messrs. C. E. Clayton and J. M. Allan.

The principles of modulation and the use of filters to create multiple speech paths over a common transmission line, are so generally known and practised, that it is easy to lose sight of the importance of carrier working in communication systems. In fact it would be difficult to visualize a large-scale communication network, of the present day, based on any other system.

Around 1932, the development of three and four channel systems showed, for the first time, that the cost of a long-distance circuit need not be directly proportional to length. This stimulus led to the development of a standard twelve-channel system which is to-day the basis of all multi-channel working. The channels are spaced 4 kc/s apart, occupying a total bandwidth of 48 kc/s.

Initially, 24 pair, low-capacitance, unloaded cables, one for each direction of transmission, were used but the demand for circuits increased so rapidly that development was concentrated on the coaxial cable. By suitable frequency conversion of the basic 12-channel group, it is to-day possible to accommodate 960 circuits on one coaxial cable.

Details were given of a wide variety of equipment in use at terminal and intermediate stations, typified by the installations at Kirkintilloch and Uddingston stations. Methods of signalling and fault finding were described. Of particular interest was the "no-break" machine set which ensures an uninterrupted power supply for amplifiers etc.

Turning to the future, it was pointed out that a 12 Mc/s system, now in existence, was likely to come into more general use. High-speed dialling over trunk circuits would also be more widely adopted. An electronic method of time assignment is being tried out on a trans-atlantic link. It provides speech paths for twice as many talkers as there are circuits. The waveguide too, is attracting much attention and if present mechanical difficulties can be overcome, may introduce entirely new concepts of bandwidth.

W. R. E.

South Western Section

The Section held its final meeting for the 1961–62 session on 18th March at the School of Management Studies, Bristol, when Mr. A. E. Crawford (Member) read a paper on "Applications and Technology of Piezo-Electric Devices". In the paper he outlined the advances achieved during the last two decades in piezo-electric materials, and then proceeded to discuss the physical properties of barium titanate and lead zirconium titanate and their use in resonant and non-resonant circuits.

Current applications of these devices include filters, ultrasonic transducers, strain-gauges, actuators and high-voltage generators. In this latter field outputs of the order of 35 joules/cm^3 are theoretically possible, but in practice heat dissipation problems set a limit to the output which can be achieved. Mr. Crawford concluded by giving a demonstration of a piezo-electric e.h.t. generator delivering 10 kV and an ignition spark generator for internal combustion engines.

G. F. N. K.

Montreal Section

At the Montreal Section's meeting on 22nd March held at the McConnell Engineering Building, McGill University, a paper on "The History and Development of Machine Tool Control" was read by Mr. W. J. Riley, P.Eng. The history of numerical machine tool control was briefly discussed and the various control applications outlined. Equipments now in production were described, and a forecast made of future developments and applications. Mr. Riley concluded his paper by showing a film "The Sperry Numerical Machine Tool Control".

K. N. C.

North Western Section

The section held its final meeting of the 1961–62 session in Manchester College of Science and Technology on 5th April. Mr. C. R. Russell, M.Sc., B.Eng., assisted by Mr. K. T. W. Milne, read a paper on "Microwave Valves". The paper was an up-to-date survey of this field and, as the principles of a number of microwave devices were discussed, Mr. Russell amplified the points under discussion by lantern slides and blackboard diagrams and Mr. Milne operated the working models and demonstrated by analogue or oscillograph.

As a historical background reference was made to the experiments at microwave frequencies conducted by Hertz in 1888 and the early difficulties experienced with the triode at the higher radio frequencies. It was explained that the triode as well as having poor noise figures at microwave frequencies suffers considerably from the transit time limitation and this, of course, limits the maximum frequency even with the best possible mechanical design.

More power, less noise, electronic tuning and wide bandwidth were all demanded as the r.f. generator is required in the higher frequency end of the spectrum. The difficulty of coping with the shorter and shorter transit times during which the electro-magnetic wave could draw power from an electron stream was discussed and the solutions presented, in their various ways, by the magnetron, klystron and travelling wave tubes were explained at some length. Mention was made of backward wave and low noise devices and the principles of parametric amplifiers, quadripole amplifiers and masers were also described.

A very large number of microwave devices, both historical and the very latest types, were on display and on completion of the paper further details were given of the various types shown. The lecturer and his colleagues are to be congratulated on the time and effort spent prior to the meeting in preparing the apparatus, working models and microwave devices on show.

F. J. G. P.

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The A.C. Coupled Shut-down Amplifier as a Safety Device in Nuclear Power Stations

By

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B.Sc., A.R.C.S.

Presented at the Symposium on "Electronic Instrumentation for Nuclear Power Stations" in London on 29th March 1961.

Summary: The shut-down amplifier supplies information to the safety circuits, so as to produce a reactor shut-down when the power exceeds a pre-determined level. A current, proportional to the reactor power, is obtained from a neutron sensitive ionization chamber. This current is compared with that obtained from a variable reference source whose output is calibrated in terms of equivalent reactor power. The shut-down amplifier gives a safe output only when the reactor power is below the reference setting. Any other condition, including fault conditions in the amplifier, must produce a trip signal. The two most essential design features of such an amplifier are absolute reliability of trip action in response to reactor power levels and low fault rate to minimize the number of spurious reactor shut-downs.

1. Introduction

It is necessary to protect a reactor against a sudden uncontrolled rise of power. This increase in power may be caused by faulty operation of the control gear or by unpredicted conditions within the core. It is important that rapid action be taken to shut down the reactor before serious damage results.

The only immediate indication of reactor power is given by the fast neutron flux which escapes from the core. A block of graphite (thermal column) placed outside the core moderates some of the escaping neutrons so that their energy is low enough to facilitate detection by a boron-lined ionization chamber. A current can be drawn from this ionization chamber, which is directly proportional to reactor power. Moreover, this current follows almost instantaneously changes in reactor power and hence can be used as a control signal of the reactor shut-down system.

2. Design Requirements

With a reactor at full power the shut-down level would normally be set at about 5% above the maximum power. Thus a reactor with a full power rating of 1000 MW would have its shut-down level at 1050 MW. However, if the power is reduced the trip margin would remain at 50 MW, hence giving a shut-down setting of 550 MW with the reactor running at 500 MW.

The shut-down level is normally set by a manual control calibrated in terms of reactor power. Alternatively, automatic setting could be adopted.

In a power reactor, the inlet and outlet coolant temperatures are constant and hence the thermal power depends on the coolant flow. Thus for safe conditions there will be a maximum specific reactor fission rate (neutron power) corresponding to a particular value of coolant flow. Thus a signal proportional to coolant flow can be used to set the shut-down level automatically. This system has not yet been used owing to the practical difficulties of measuring total coolant flow in a reactor having several cooling circuits. However, the possibility of this type of control cannot be ignored and the shut-down amplifier must be designed to incorporate such a facility.

The response time of the system should be as short as possible and a figure of 50 milliseconds would be reasonable for the electronic portion of the system. The response time of the control rod system will not be considered in this paper.

The safety circuits of the reactor are usually triplicated and a shut-down is initiated only when at least two safety lines have tripped. Thus it is necessary to use three shut-down channels each capable of being set to the same level, within a tolerance of ±1 MW. Thus a setting accuracy of ±0·1% is required on the trip level.

The shut-down system must be absolutely reliable in its response to a genuine trip signal. Failure to bring about a shut-down on a real power excursion could lead to disaster. To this end the system must be designed so as to "fail safe", that is a fault in any part of the system must lead to a trip condition in that channel. In order to avoid spurious shut-downs the system must have a very low failure rate. In addition

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[†] General Radiological Ltd., Stanmore, Middlesex.

it is usual to use three parallel systems with a shut-down only if two or more channels trip.

3. A Practical Amplifier

The current from the ionization chamber flows through a fixed resistor. The voltage across this resistor is thus proportional to reactor power. A very stable voltage is provided by running a reference neon tube under constant current conditions. This voltage is divided down by means of an accurate multi-turn linear potentiometer. The voltage at the slider is used as a reference and is calibrated in terms of reactor power. The reference and power signals are compared and a "safe" output is obtained only when the reference exceeds the power signal. If the power signal equals or exceeds the reference or on any system fault a trip output is required. A voltage proportional to coolant flow may also be used as a reference (Fig. 1).

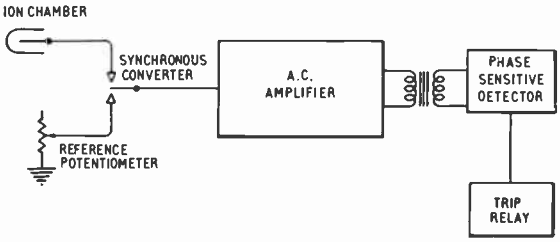

Fig. 1. Schematic of the basic shutdown amplifier.

The difference amplifier normally comprises a synchronous converter which connects alternately the reference and power signals to the input of an a.c. amplifier. The output of this amplifier is rectified by a phase-sensitive detector and holds a relay energized. The relay is polarized and holds on only for a positive output which is obtained when the power signal is below the reference level. This represents the safe condition. The trip condition is when the relay is released. This occurs when the power signal rises above the reference or when a fault in the amplifier reduces its output to zero. Thus the amplifier tends to fail safe for most conceivable fault conditions. If the gain is reduced, but not to zero, a trip will be obtained at a lower power than the set level. This also constitutes a safe failure.

In order to obtain a sharp trip point, the gain of the amplifier is made high so that the last stage saturates when the power signal is more than a few megawatts below the shut-down level. Indication of trip margin is obtained by measuring the amplitude of the square waveform in the early unsaturated stages of the amplifier.

The present generation of power reactors are fitted with shut-down amplifiers using valves. The trip amplifier just described comprises two double triode valves, a synchronous converter and a transformer-coupled phase-sensitivity detector employing two selenium diodes. Thus the circuitry is very simple and has proved very reliable in service. Nine amplifiers have been operating continuously at Bradwell power station for over 6000 hours; to date no failures have occurred in this part of the circuit.

Trip margin indication requires only one triode valve and a second phase-sensitive detector. However it is a requirement in nuclear power stations that a warning be given as a trip point is approached. In addition a second warning is necessary to indicate to the operator when the reactor power has fallen so far below the shut-down level that adequate protection is no longer provided. These two alarms are normally termed "low" and "excess" margin respectively. These additional facilities add complication to the complete instrument but do not affect the vital trip action (Fig. 2).

The instrument is required to maintain satisfactory operation during changes in mains voltage of -20% to $+10\%$ of nominal. The trip point is not materially affected by such changes. There are some variations of margin indication and alarm levels, but these are of secondary importance.

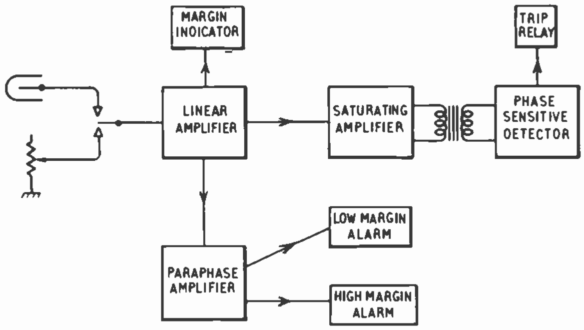

Fig. 2. Schematic of typical amplifier used on power reactors.

The circuit of an actual shut-down amplifier is shown in Fig. 3. The two halves of V1 form a linear amplifier with negative feedback. V3a and V3b form a cascaded amplifier without feedback so that overloading occurs for a very small input signal. The a.c. output of V3b is rectified by a phase-sensitive detector to hold on the trip relay RLA. Trip margin indication is obtained from the square wave at the anode of V1b. A synchronous converter is used in the phase-sensitive detector in the cathode of V2a, in order to obtain accuracy of indication. The reference voltage is derived from an 85-volt reference

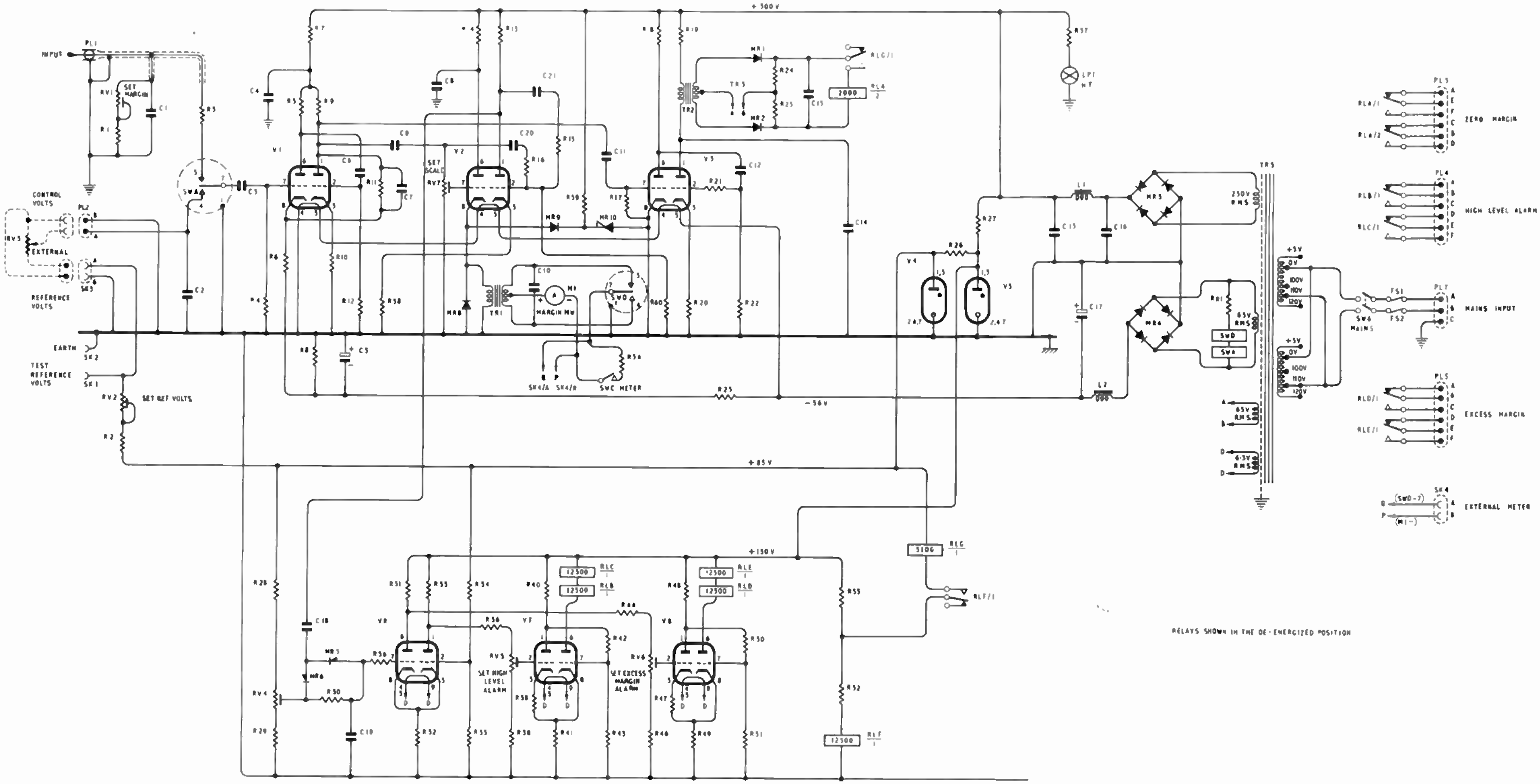

Fig. 3. General Radiological shutdown amplifier type NE 048 C as used at Bradwell Nuclear Power Station.

neon V4. Failure of this neon causes a rise in the reference voltage, releasing RLG which in turn releases the trip relay RLA. Ancillary alarms are provided by V7 and V8 with associated relays.

The synchronous converters are manufactured by George Kent Ltd., and contain low voltage and high voltage contacts. The low voltage contacts have a sliding action and this leads to a high degree of reliability. The low voltage contacts only are used in the shut-down amplifier, hence necessitating the use of two converters. Synchronism is ensured by operating the driving coils in series. Only one failure has occurred in a total of 200 000 converter-hours. This is with a sample of 36 converters, half of which have now run for over 8000 hours. The failure occurred in a converter which had operated for a few hundred hours only.

4. Limitations of the System

Although the amplifier itself can be made fundamentally "fail-safe", there are two possible faults which would not cause a trip. The first is the failure of the polarizing supply to the ionization chamber, the second, a discontinuity in the ion chamber signal cable. However, in the case of a reactor working above a power equal to the "excess margin" alarm level, this alarm will be brought up. The operator will then find that the trip margin indication on one amplifier is much greater than the other two. Although this may prove adequate it would be preferable to make both the above faults produce an automatic trip.

The polarizing supply may be monitored by a simple voltage-sensing circuit. The ion chamber connections can be monitored by injecting a small high frequency signal into the polarizing supply. This frequency can then be detected at the input to the shut-down amplifier, amplified and used to hold on a relay. The contacts of the relays in the two failure circuits could then be placed in series with those of the trip relay. As the reliability of both the polarizing voltage generator and the cable connections can be made of a very high order, it is likely that the fault rate of the two monitoring circuits would greatly exceed that of the functions they were monitoring. Thus for this reason it is not recommended that such measures be adopted. The basic reliability of the shut-down system depends on its simplicity and any complication must be weighed very carefully against the inevitable increase in spurious trip rate.

It has been suggested that an a.c. polarizing signal be used. This would solve the problem of ensuring that the ion chamber polarizing supply and ion chamber connections were intact. A synchronous converter would not now be required and the a.c. amplifier would receive a direct signal. Although this system at first sight seems very attractive, it is fraught with difficulty owing to the very complicated behaviour of an ion chamber with a.c. polarization. Undoubtedly such a system could be made to work but in order to meet the present requirements for power reactors it would be very complicated. Simplicity is a fundamental to long-term reliability.

Although current designs of shut-down amplifier have some limitations, they are basically very simple and a high degree of reliability is obtained. Some improvement could probably be obtained by using transistors but it would be difficult to retain a high input impedance which is necessary in present applications. The best solution is probably a hybrid circuit containing both valves and transistors. It may be necessary to retain the mechanical synchronous converter, but experience so far has shown them to be extremely reliable, provided they are used correctly.

5. Acknowledgment

The author wishes to thank the directors of General Radiological Ltd. for permission to present this paper.

Manuscript first received on 28th November 1961 and in final form on 22nd February 1962 (Contribution No. 52).

U.D.C. 522.6 : 621.396 : 629.19

Radio and Photographic Observations of Artificial Satellites

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Presented at the Convention on "Radio Techniques and Space Research" in Oxford—5th to 8th July 1961.

Summary: Methods of photographic, radio and radar observation of satellites are discussed, together with methods of analysing these observations. The results of analysis yield information about the orbit of the satellite, and hence about effects of gravitation, atmospheric drag, and radiation pressure on the orbit. Radio observation also gives information about the effect of the ionosphere on radio waves. Although the early promise of this method of ionospheric investigation has not yet been realized, it is to be expected that it will be of considerable importance in the future. Some observations and photographs are presented and discussed. 51 references.

1. Introduction

Signals from artificial satellites must penetrate the atmosphere by one of its "windows", i.e. either on radio frequencies between 10 Mc/s and 40 000 Mc/s or in the optical (or near optical) part of the spectrum. Such signals may give information about

(i) the performance of equipment in the satellite (i.e. telemetry),

(ii) the position and orientation of the satellite,

(iii) the medium through which the signals are propagated between the satellite and earth.

It is the purpose of this paper to give an account of the type of observation and analysis required in order to obtain information of the second and third kinds.

2. Radio Observations (Amplitude and Polarization)

A radio wave has amplitude, phase, frequency, and polarization; for a radio wave received on the ground from a satellite, these parameters vary both in space and in time. If the satellite is radiating c.w. (and for many purposes this can be assumed to be so), the variations in amplitude and polarization are due to changes in the position of the satellite, changes in the attitude of the satellite, and changes in the propagation path. Changes due to the position of the satellite (i.e. due to the distance between satellite and observer and to the polar diagram of the observer's aerial) usually take place very slowly; on the other hand changes in amplitude and polarization due to changes in satellite attitude may be quite rapid. Most satellites are "spinning" or "tumbling" in a regular way, with a definite period which remains constant over many months. If the manner of tumbling is known, then its effect can be allowed for in analysing the observations: if it is not known, then it may still be possible to disentangle the effect of tumbling from the effect of the propagation path, since the tumbling effect is regular, with a definite constant period, and is independent of the radio frequency used.

When effects due to the changes in position and attitude of the satellite have been eliminated, we are left with effects due to the changes in propagation path. The effect of the troposphere on the radio wave is merely to cause a small amount of bending; this affects neither the amplitude nor the polarization. There are, however, two important effects due to the ionosphere.

A "smooth" ionosphere, i.e. one in which the electron density varies only gradually with latitude, longitude, and height, causes bending of the radio wave and changes in its polarization. If a plane polarized wave is radiated from the satellite, then its plane of polarization is rotated as it passes through this ionosphere. The total rotation is proportional to the total number of electrons in a column between the observer and the satellite, and to the component of the earth's magnetic field along this column, and inversely proportional to the square of the frequency. In order to determine this number of electrons it is necessary to find the total rotation, which may amount to many complete revolutions. The number of complete revolutions may sometimes be found, either by measuring from the instant at which the line joining the satellite to the observer is perpendicular to the earth's magnetic field, and so the rotation is zero, or by comparing the polarization on adjacent frequencies. It is also necessary to know the earth's magnetic field in the ionosphere; this is subject to some uncertainty.

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As the satellite moves, so the number of electrons in the column joining the satellite to the observer changes, and so the total rotation of polarization changes. The polarization of the received wave changes, and this normally causes changes in the voltage in the receiving aerial; in fact the polarization at any instant can usually be deduced by noting the voltage received on a single linearly polarized aerial. Sometimes two separate aerials at right angles to each other have been used, but since the voltages in the two aerials differ from each other merely by a slowly varying amplitude factor and a predictable "phase" (i.e. phase of fading, not to be confused with radio frequency phase), the record of voltage in the second aerial contributes no additional information.

The changes in amplitude described in the previous paragraph are regular, being nearly sinusoidal. Sometimes irregular variations occur; records which show this effect are easily distinguished from those which do not. The effect is due to inhomogeneities in the ionosphere, which also contribute to fading of ground-to-ground transmissions via the ionosphere, and to the twinkling of radio stars. Satellite records show that the effect, which is usually called "scintillation", occurs much more often when the satellite is north of Britain than when it is south; this suggests that the inhomogeneities are associated with the aurora.

Detailed theoretical interpretation of a record showing scintillation is complicated, but for signals from terrestrial transmitters and radio stars some success has been achieved by concentrating on the times of maxima and minima on spaced receivers. This technique is now being applied to signals from satellites, and is expected to yield useful results, about both the extent and the height of the inhomogeneities. Since the satellite is moving horizontally very rapidly, the information obtained is likely to be different from, and additional to, that obtained from spaced receiver experiments using terrestrial radio transmitters or radio stars.

3. Radio Observations (Phase and Frequency)

Observations of amplitude and polarization give no information about the position of the satellite. For this purpose observations of phase or frequency are necessary. Two types of observation have been widely used—interferometer and Doppler. Both types of observation may also give some information about the medium of propagation, i.e. the ionosphere.

Probably the most important radio observations made on satellites have been those of the phase of the carrier frequency. This is the basis of the Minitrack system, which is the usual radio method used by the Americans to locate their satellites. The system consists of two interferometers, one with aerials separated in the North-South direction and the other with aerials separated in the East-West direction. The phase differences between the signals received on the two members of each pair are continuously measured and recorded. Accurate analysis of the records yields the direction of arrival of the signal at any instant to an accuracy of a few minutes of arc. The system is calibrated using an aircraft whose position is observed photographically; the calibration is repeated from time to time.

It is possible also to locate the satellite by merely observing the frequency of the received signal. The path length between satellite and observer is usually changing rapidly, at a rate of up to about 8 km/s. If the wavelength is 2 metres (i.e. the frequency is 150 Mc/s), this is equivalent to 4000 wavelengths per second; the frequency received is therefore 4 kc/s different from that radiated. If the frequency radiated is known exactly, then a record of the frequency received gives exact information about the rate of change of path length during the interval of observation. This information is in a sense complementary to that obtained from the interferometer in that it gives information about how far the radiation has come, while the interferometer gives the direction from which it arrives.

A satellite orbit has six parameters (inclination, semi-major axis, eccentricity, longitude of node, argument of perigee, and time at node (see Fig. 1)); it is clear that, if either direction of arrival, or path length, or both, are accurately recorded over several minutes, then it is possible to deduce a unique set of six parameters which fit the recorded data. In fact, this has been done using a curve of frequency against time for a single observed transit (such a curve is usually called a "Doppler curve"), but much greater accuracy can be obtained by using one or two curves from each of three or four observing stations. Although it is possible to deduce something about the orbit by simple measurements on an observed curve (either interferometer or Doppler), it is usual, and much more satisfactory, to use a computing machine. The use of such a machine is greatly facilitated by making all the records in the same standard form. This is done for the Minitrack interferometer, and for the Doppler records obtained from the *Transit* satellites. Many Minitrack stations have been supplied by the Americans and installed all over the world. The most accurate interferometer observations of satellites in this country are likely to be those obtained by the Minitrack equipment operated by the Radio Research Station, Slough. The most accurate Doppler records are probably those obtained by the equipment at R.A.E., Farnborough, for observing *Transit* satellites. Records from both of these equipments are sent to U.S.A. for analysis.

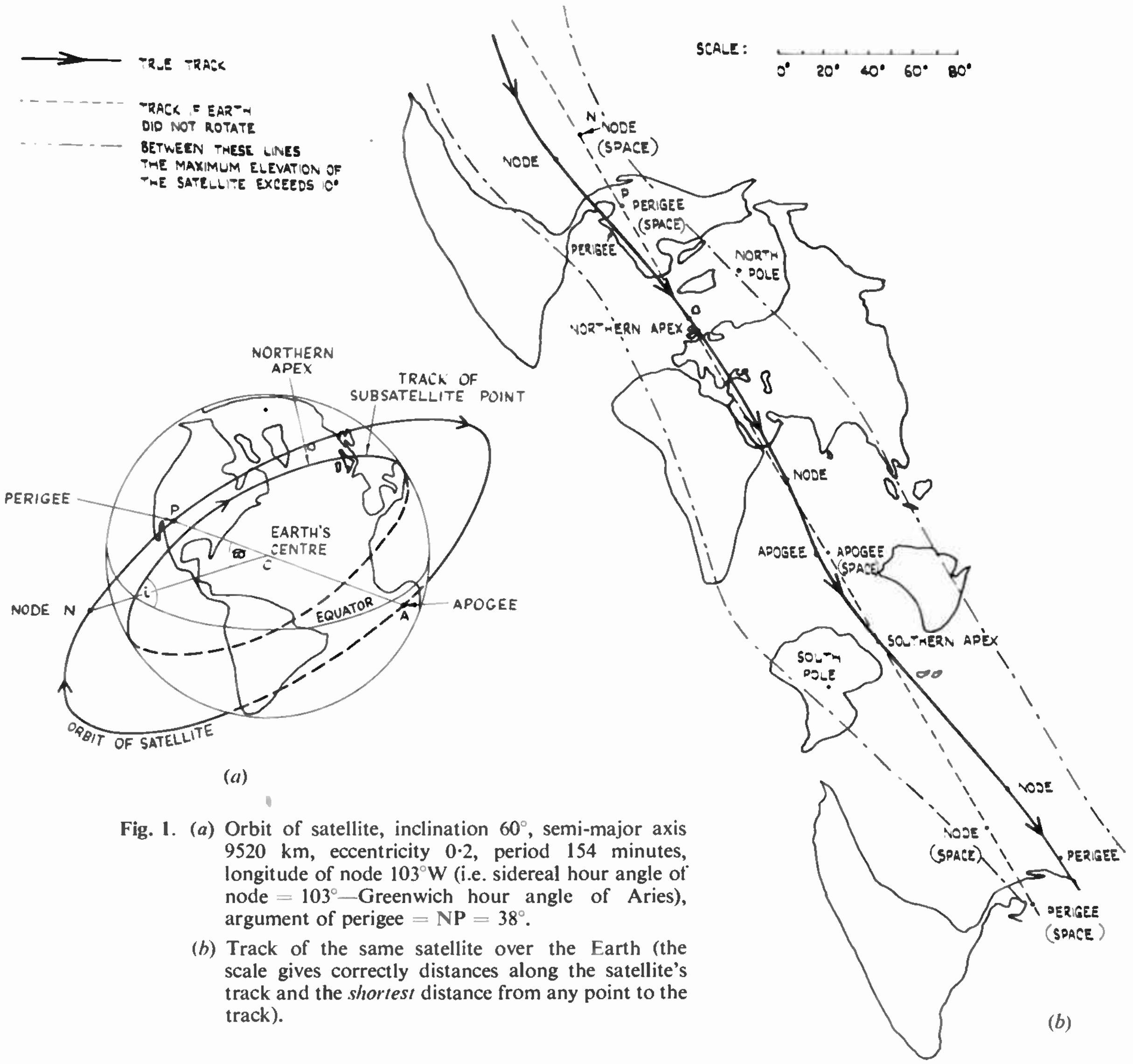

Fig. 1. (*a*) Orbit of satellite, inclination 60°, semi-major axis 9520 km, eccentricity 0·2, period 154 minutes, longitude of node 103°W (i.e. sidereal hour angle of node = 103°—Greenwich hour angle of Aries), argument of perigee = NP = 38°.

(*b*) Track of the same satellite over the Earth (the scale gives correctly distances along the satellite's track and the *shortest* distance from any point to the track).

Exact observations of phase or frequency also give information about the medium of propagation, i.e. the ionosphere. Since the refractive index of the ionosphere is less than unity, the number of wavelengths in the path between satellite and observer is less than it would be in free space, and this difference changes during the transit of a satellite according to the amount of ionosphere which this path traverses; this affects the amount of the Doppler shift and the shape of the Doppler curve. Also the bending of the radio wave in the ionosphere causes changes in the direction of arrival of the received wave, and so affects the interferometer record.

In obtaining from the records information about the position of the satellite, allowance must be made for ionospheric effects. This can be done either by assuming a particular model ionosphere or by making observations designed to find the magnitude of the ionospheric effect. The best way of finding the ionospheric effect appears to be measuring the Doppler shift on two harmonically related frequencies. Since the departure from unity of the refractive index of the ionosphere varies inversely as frequency squared, the Doppler shift on a frequency f may be expressed as $Af+B/f$, where A and B are both functions of time. Observation on two frequencies simultaneously enables A and B to be separated, thus yielding both A, the effect corresponding to the motion of the satellite in free space, and B, the effect of the ionosphere. If the two frequencies used are harmonically related, then the separation into A and B can be carried out electronically, using frequency multipliers. In this arrangement, an oscillator is locked in frequency to the incoming signal on the lower frequency, the output of the oscillator is frequency multiplied by the appropriate constant, and this is compared with the frequency of the incoming signal on the higher frequency. The difference between these two frequencies, which usually varies from zero up to a few cycles per second, is very nearly proportional to the Doppler shift multiplied by the number of electrons in a column between the satellite and the observer; this simple expression applies only if the satellite is flying at constant height and the effect of ionospheric refraction can be neglected. If these conditions are not satisfied, the computation is rather complicated.

Recently some useful results concerning the ionosphere were obtained by the differential Doppler method by workers at the Cavendish Laboratory, Cambridge; these used observations of c.w. signals from *Sputnik 3* taken during March 1960 at Stanford, California. The satellite observations indicated that the electron density between 90 and 100 km was greater than that which had been assumed in reducing the data from the normal ionospheric sounder; otherwise the results from satellite and sounder were in agreement. The observations were all near local noon; the satellite height was 175 km. The curve of differential Doppler against time was irregular, thus revealing considerable horizontal irregularities in the ionosphere. The method employed in this analysis could be used to analyse observations on the forthcoming Ionosphere Beacon Satellite and on the series of *Transit* satellites. Although information gained about the ionosphere from reception of signals from satellites has been so far disappointingly small, it is to be expected that in future routine observations of satellites such as *Transit* will yield useful information supplementary to that obtained by sounding the ionosphere from the ground. "Topside sounding" from satellites will also yield useful information, but that is outside the scope of this paper.

The prime purpose of observations of phase and frequency of signals from a satellite is to find out where the satellite is. From this its orbit, and hence the effect of the earth's gravitational field, the drag of the atmosphere, and other perturbing factors, can be found. It is also necessary to know where the satellite is in order to appreciate the significance of the telemetered data. But another very important use has been made of observations of frequency. This is, in effect, the reverse problem—given the position of the satellite, find out where the observer is. If a Doppler curve is observed, and both the elements of the satellite's orbit and the frequency transmitted from the satellite are known, then it is possible to find a unique position of the observer which will be in agreement with the observations. If the frequency transmitted is not known, then it is possible to treat it as an unknown, and to find both it and the observer's position from the observations. This is the system of navigation by means of the *Transit* satellites. Three experimental satellites have already flown, and it is hoped that there will be a partially operational system in 1962. It relies on a stable transmitter frequency, a stable reference frequency on the ship, means of discovering and disseminating exact information about the satellite's orbit, and means of finding time accurate to 0·1 seconds or better. Two harmonically related frequencies are used, e.g. 54 Mc/s and 324 Mc/s, in order to provide means for finding and eliminating the effect of the ionosphere.

The observations of frequency of the received signal during a passage of the satellite lasting five minutes or so, together with the elements of the satellite's orbit, are fed into a computer on the ship, which determines from them uniquely the latitude and longitude of the observer. There are various ways of performing this computation, and the method recommended by the U.S. Navy has not been published. But any method can do no more than determine effectively the time of closest approach (this is approximately the time when the rate of change of frequency is greatest), and the distance of closest approach (this is approximately inversely proportional to the greatest rate of change of frequency). For this reason, if the satellite flies nearly overhead, the method gives very little accuracy in the direction perpendicular to the direction of motion of the satellite; this is a fundamental drawback of the system. The final accuracy aimed at, for a transit not too nearly overhead, is ± $\frac{1}{4}$ mile.

Since every operational observation of a *Transit* satellite must contain information about the number of electrons between the satellite and the observer, this would appear to be a good method of investigating the ionosphere.

4. Radar Observations

Several radar observations of satellites have been made. In order to observe a satellite at all with an ordinary pulse radar, high power and high gain are necessary; a low noise receiver is also advantageous. The requirement of high gain means that an aerial with a narrow beam must be used. The problem then arises of ensuring that the satellite will fly through the beam; this necessitates accurate prediction of satellite position. Such radar observations cannot therefore be used to find the position of the satellite, merely to verify that it appears at the expected place at the expected time. The only item of information obtained is the echoing area of the satellite, which can be found from the strength of the received signal. This is of no great importance, except for satellites, such as *Echo*, which are intended to be used as reflectors of radio waves.

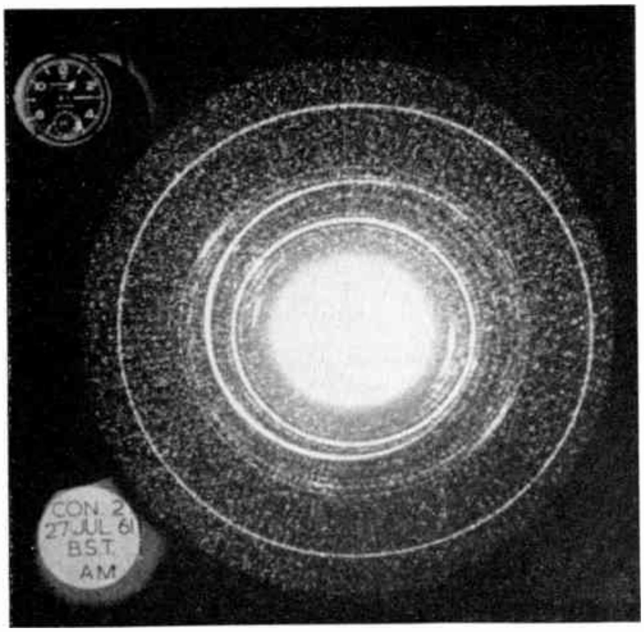

Fig. 2. Radar reflection from *Echo 1* observed from Bushy Hill, near Chelmsford, Essex, at 00h 15m G.m.t. on 27th July 1961.

A special radar system for satellite watching has been set up in U.S.A. This uses a c.w. transmitter of power 50 kW on a frequency of about 100 Mc/s, feeding an aerial whose beam is wide in the EW direction and narrow in the NS direction. There are two receiving aerials, some distance away from the transmitter; each has the same polar diagram but is also arranged as an interferometer, with EW separation, i.e. there are two receiving aerials separated in the EW direction. The angle of arrival in both planes can thus be found. This system is of such sensitivity that it can observe the smallest satellite, *Vanguard 1*, a sphere of diameter six inches. This radar system is probably the only one which can be relied on to keep track of all objects in orbit (except those which are very small or in orbits of low inclination) and to detect new satellites.

Although most radars have been designed for looking at aircraft or ships, some have been specially designed for looking at objects in the high atmosphere. These may be capable of seeing satellites flying through the volume covered by the radar; the predictable passages of satellites may be used to check the performance of such radars. Included in this category are radars for the investigation of meteors, aurora, and back-scatter via the ionosphere, as well as those intended for tracking man-made objects in the high atmosphere.

Figure 2 shows a radar reflection from the satellite *Echo 1* flying through the beam of a fixed parabolic aerial of diameter 30 ft; the frequency was 1300 Mc/s and the width of the radiation pattern about 1·8 deg. The time base was rotating at 4 rev/min., and the portion displayed shows echoes between 0 and 40 n.m., 324 and 364 n.m., 648 and 688 n.m., 971 and 1011 n.m., and so on. The reflection from the satellite is the only spiral line in the display; it lasted for about twelve seconds (the time taken for the satellite to fly through the beam), the range increasing from 992 n.m. to 1000 n.m. during this time.

5. Optical Observations (Visual)

The information gained from the optical observation of a satellite's track in the sky is used for two main purposes. Initially and soon after launching visual observations may be made complementary to radio observations, and in the case of radio failure they become the sole means of detecting the satellite and of ascertaining its approximate orbit. Later, that is as soon as sufficient information about the orbit is available to enable a camera to be pointed at a region of the sky through which the satellite is expected to pass, photographic records may be obtained which will yield precise data about its orbit. This information, together with less accurate visual and radio observations, has been used with great success to deduce facts about the earth's gravitational field and the drag due to the atmosphere.

A satellite's orbit is computed from a number of observations of its position at known times relative to the star background; the crudest observations may be made visually by estimating the satellite's position on a line joining two known stars at a time obtained by stopwatch subsequently compared with a source of standard time, e.g. the "speaking clock" on the telephone. This sort of observation (accuracy about 1 degree and 1 second) is the most common form of optical observation, and although it is not very accurate it has been very effective in finding changes in the period of the satellite and in the Right Ascension of the node. Visual observations have in fact been necessary in order to show the correlation between atmospheric drag and the activity of the sun, since photographic observations are not usually made sufficiently often to enable the variations in drag to be followed in detail. Visual (or radio) observations are also necessary in order to be able to predict accurately enough for observation by cameras or kinetheodolites to be possible. Some satellites are bright enough to be observed by the naked eye, but for others an optical aid (telescope or binoculars) is necessary; it is best to use an instrument with low magnification and wide field of view. It is interesting to record that during May 1961 Radio Research Station received more than 1000 visual observations on 21 different satellites.

Some visual observations are made by individual observers, but others are made by a team of observers; this system of observation is called Moonwatch. Each Moonwatch team consists of up to 15 observers equipped with binoculars or small telescopes mounted firmly on fixed supports so that each observer looks at a fixed region of sky to give overlapping coverage along the meridian plane. Instruments of about 50 mm aperture are used with wide-angle eyepieces having magnifications of 6× or 7× covering a field of about 10 deg. The observer who sees the satellite notes the time of meridian passage, a meridian marker being provided for aligning the telescope. He also estimates the zenith angle using either a scale or the star background, and if possible notes the satellite's path which he subsequently draws in on a star chart.

Some requirements are common to visual and photographic observation. The site should be fairly open with full view from the zenith down to about 20 deg and be protected from the glare of local lights. Observations are often not possible less than 20 deg or 30 deg above the horizon because the satellite is too faint, partly because of its increased distance from the observer and partly because of atmospheric absorption. Since the light from the satellite is reflected sunlight, the satellite must be outside the earth's shadow so that it is illuminated by the sun; the observing station, however, must be at least in twilight, so that the sky is reasonably dark. Observation is thus possible when a satellite passes near the observer either shortly after sunset or shortly before sunrise. There are usually two belts of latitude within which the satellite is visible, one belt allowing observation before sunrise and the other after sunset. The boundaries of these belts change as the orbit of the satellite changes, and as the declination of the sun changes. A particular satellite can usually be seen by a particular observer every evening or every morning for two or three weeks at a time, assuming that the skies are clear; there may be periods of up to five weeks when the satellite is available to this observer in neither the morning nor the evening twilight.

6. Optical Observations (Photographic)

A photographic record of the satellite's position in the star field is useful because it can be measured at leisure, thus removing a large source of personal error. How then is this record to be obtained and what considerations are involved? For example, what area of the sky is to be covered and is the camera to remain still while the stars and satellite go by or should the camera follow the stars (or the satellite)?

The problems have been answered in different ways, by different authorities and the method used has of course to be governed by a large number of factors including the effort and finance available.

The American *Phototrack* programme sponsored by the Society of Photographic Scientists and Engineers made (among others) the following recommendations:

> The negative should be at least 4 in × 5 in.
>
> The lens should be at least 5 in focal length.
>
> The satellite track should be photographed against a star background with two gaps or discontinuities timed to 0·1 second.
>
> Fast emulsions of at least 200 ASA should be used with as wide an aperture lens as possible.

The observations were intended to supplement the information already provided by other methods and no great claims were made about their accuracy.

One of the most elaborate conceptions is the Baker-Nunn satellite tracking camera developed by the Smithsonian Institute Astrophysical Observatory. This uses a Schmidt type optical system with a 31 in mirror working at *f*/1. It covers a field 5 deg × 30 deg on a strip of film about 2 in × 12 in and can take photographs at rates from 1 to 32 per second. The film used has a speed rating of 800 ASA. The camera is carried on a form of altazimuth mount which is capable of being driven automatically at the satellite rate (in which case the stars trail) or at sidereal motion rate (when the satellite trails). A special shutter produces sharp breaks in the trails. The timing system makes use of radio signals, and a crystal clock which is photographed on the film and which can be read to 1/10 millisecond. The expected accuracy of observation is 2 seconds of arc at 1 millisecond. Stars of magnitude 13 or greater have been recorded with this camera. (A 6 in satellite at 2500 miles has been recorded.)

A somewhat simpler fixed camera developed by R.R.E. uses a 36 in focus lens of 6 in aperture covering a 14 deg square field. The satellite track is photographed against a trailing star field, the shutter being momentarily closed by electrical pulses at $\frac{1}{2}$ second intervals. The time of these operations is checked by radio time signals omitting selected pulses on a program basis for recognition purposes. Since the stars move across the field much slower than the satellites, the breaks in their trails may not be well resolved, so in order to determine the orientation of the camera from the star field supplementary breaks of longer duration are made before and after the satellite's transit. Individual positions may be determined to ±3 seconds of arc and time to 1 millisecond. Smoothing a number of measurements improves this slightly. The limiting brightness appears to be about magnitude 5.

For our first photographic observations in January 1958 (following earlier radio and visual observations), we set up a standard 4 in × 5 in technical camera with a 135 mm $f/4{\cdot}5$ lens to photograph the trail of *Sputnik 2* using plates with a speed of ASA 400. It was soon realized that better results would be obtained with a wider aperture lens and having acquired a 7 in $f/2{\cdot}7$ Aero Ektar an adaptor was made to fit this to our camera. The increased weight of this large lens proved to be a serious drawback as focus could not be maintained when the camera was tilted back to look up at high altitudes. A simple aluminium box was therefore constructed with the lens in a screwed "focusing" mount on the front and a plate holder behind. The lens was focused on infinity by trial and locked in position. A large shutter was attached to the front of the lens, its "flash" contacts being used to record the time of opening. In practice this shutter, which was normally held open manually during the satellite's transit, was closed for short durations with a rough program, signals from the shutter contact being recorded on tape simultaneously with time signals. Before and after transit, longer shut intervals were introduced to give the desired breaks in the star trails.

Early in our experience it was realized that accurate results could not be expected from a camera mounted on a simple tripod, which also did not allow easy orientation and elevation. Fortunately a small searchlight mount was available; this was modified to take the camera and turned out to be a most useful and very rigid piece of equipment.

Some photographs taken at Marconi's Research Laboratories are shown in Figs. 3, 4 and 5. Figure 3, showing *Sputnik 2* on 11th April 1958, two days before its final descent into the atmosphere, is one of the few photographs which have been properly analysed, and will be discussed below. The brightness of the satellite was varying in a typical way, being between first and second magnitude at its brightest, and fading to fourth magnitude or fainter for perhaps ten seconds at a time; such a fade is clearly seen in the top right hand corner of Fig. 3 (shortly after leaving the field of view of the camera the satellite became bright again). The breaks in the track were obtained by closing and opening the shutter, at times which were accurately recorded.

With our camera, only satellites of the third magnitude and brighter can be photographed. In addition to several photographs of *Sputnik 2*, we have also taken photographs of *Sputnik 3* and its rocket, of *Sputnik 4*, its rocket and its cabin, and of *Echo 1*.

For some weeks after *Echo 1* was launched, on 12th August 1960, its brightness was steady (Fig. 4), but towards the end of August the brightness started fluctuating considerably. This was because the satellite lost its spherical shape, probably because its temperature dropped sharply when it entered the earth's shadow for the first time on 23rd August. These considerable and irregular fluctuations in brightness are shown clearly in Fig. 5. Also shown in Fig. 4 is a simple method for finding the time and position of a single point on the satellite's track; the

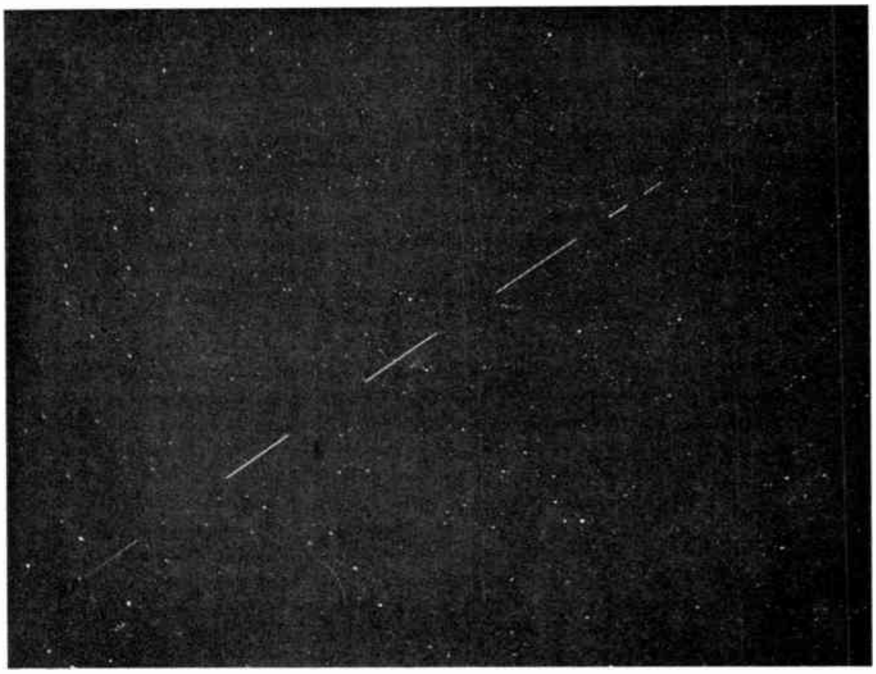

Fig. 3. *Sputnik 2* (1957 β), 11th April 1958, Cassiopeia to Ursa Minor.

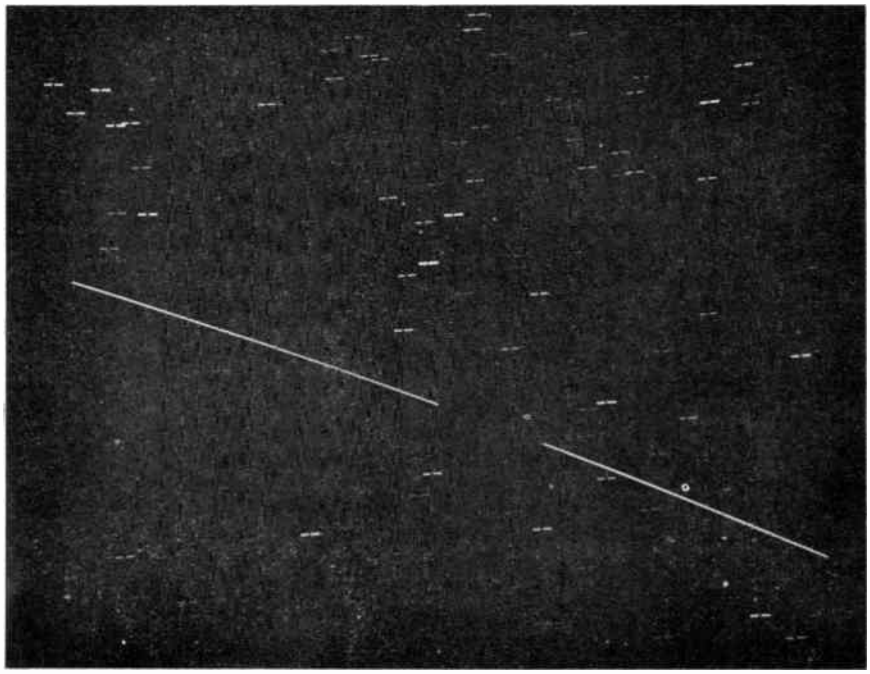

Fig. 4. *Echo I* (1960 ι 1). 16th August 1960, passing through Aquila.

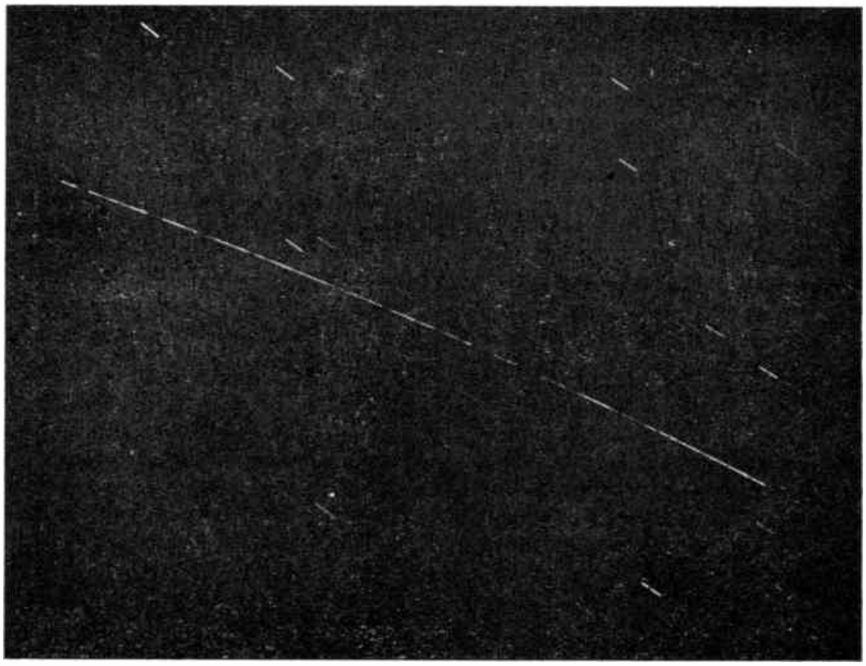

Fig. 5. *Echo I*, 10th September 1960, from above δ Serpentis to near β Ophiuchi.

break is made sufficiently long for a clear break to appear in each star track. It is worth noting that the magnitude of *Echo* is not now fluctuating as in Fig. 5 but is almost steady again; the reason for this is not clear.

An instrument which has been used with considerable success for the photographic observation of satellites is the kinetheodolite. This is essentially a motion-picture camera having a long-focus lens, attached to a theodolite in such a way that the field viewed through the theodolite is recorded on film, and has automatically superimposed on it at least a pair of cross wires or a graticule, with the necessary scales to indicate the setting of the theodolite, together with some means of recording time.

The Askania instrument used by the Royal Aircraft Establishment has a specified accuracy of 15 seconds of arc with a timing accuracy of better than 1 millisecond. It is manned by a pair of operators controlling its altitude and azimuth who try to follow the target whilst it is photographed 4 or 5 times per second. The graduated scales are illuminated by a flashing light source at the same time as each picture is taken.

Imperfect tracking by the operators may introduce some additional error due to the target image on the film becoming a line rather than a spot but this error seldom exceeds 20 seconds of arc.

7. The Analysis of Records

Obtaining radio and photographic records from satellites may require special equipment, and certainly takes some time and trouble. But the exact analysis and interpretation of these records takes much more time and trouble. For example, it is easy to record frequency of the received signal from a satellite as a function of time, using a frequency meter and a pen recorder. Provided that a sufficient amount of the Doppler curve is available, such a record can be simply analysed graphically: the point of maximum slope can be found by symmetry, and the frequency and rate of change of frequency at this point can be read and measured on the graph. One additional observation of the exact time at which a particular frequency is reached is necessary in order to find the time of maximum slope (i.e. maximum rate of change of frequency) with sufficient accuracy to be useful, i.e. ± 1 second or so.

A more accurate record of frequency could be made by photographing a counter every fifth of a second or so. This record contains a great deal of information, and the complete analysis of such a record, or of a complete interferometer record, is quite a tedious and complicated business. In fact, it is so complicated that the only reasonable solution is to record the data in such a form that it can be readily fed into an automatic computer; this is the reason for the complex recording arrangements which are standard for Minitrack and *Transit* receiving stations. Some useful information can, however, be obtained without using a computer; this includes rough measurements of position (nearly all early measurements on *Sputnik 1* were of this kind), and the "differential Doppler" method of investigating the ionosphere, although the latter can be carried through without a computer only if the satellite is flying nearly horizontally and ionospheric refraction can be neglected.

When we took photographs of *Sputnik 2* in 1958, we supposed that other people interested in the orbit would be keen to analyse our plates. We discovered that, although R.A.E., Farnborough, were very willing to analyse photographic observations in the form of observed coordinates, they were not very willing to obtain the coordinates themselves by reading our plates—this is in fact quite a tedious process. Finally we read one of our plates, and R.A.E. read one other. They fed these readings to a computer which

(i) calibrated the plate in altitude and azimuth, using the observed coordinates of stars, the known time of observation, and the latitude and longitude of the observer,

(ii) found the altitude and azimuth of the points observed on the satellite track, and

(iii) found the elements of the orbit which gave the best fit to these observed points.

In some star photographs there is difficulty in identifying the stars; this was not the case in any of our photographs, because the field of view was so large (50° × 36°) that some easily recognizable star or constellation was always included; also the motion of the stars was sufficient to indicate clearly the direction and distance of the North Pole.

The plate shown in Fig. 3 was read on the Zeiss plate reader at R.R.E., Malvern, which is probably the most accurate instrument of its kind in this country. Coordinates of twelve stars and the beginnings and ends of satellite trails were recorded in units of one micron. The true positions of these stars on the date concerned were found from their coordinates in a star catalogue, together with corrections for proper motion, precession, nutation and aberration. The effects of atmospheric refraction were taken into account by the programme for calibrating the plate. The observed coordinates of the twelve stars, the true positions of these stars, the time of the star observation, and the coordinates and times of satellite observations, were supplied to R.A.E. The latter times were measured, by pen recorder on paper tape, with an accuracy of about 0·01 seconds relative to each other—the absolute accuracy was about 0·1 second.

The star exposure took place a few minutes before the satellite flew past, and lasted for about 2 seconds, the times of opening and closing the shutter being recorded on paper tape. Since the stars were not far from the North Pole, they moved by amounts up to about 15 seconds during the exposure, thus making a dot on the plate up to about 10 microns long. The dot corresponding to each star can be seen on Fig. 3 at some distance from the corresponding star trail. The crosswires of the plate reader were lined up by eye on the estimated centre of the dot; the stars used were of magnitude between 5½ and 7, since brighter stars produced too large dots, while fainter stars could not be seen. The calibration by computer showed that the r.m.s. error in star positions was 4 microns on the plate, which corresponds to 6 seconds of arc.

The third stage of computation showed that the r.m.s. errors in satellite position were 20 microns, or 30 seconds of arc. This was partly due to the difficulty of deciding exactly where the ragged end of a satellite track should be taken to be, and partly to the error in measuring time. The satellite speed was just less than 1 deg/s during the observation, which corresponds to a movement of the order of 30 seconds of arc in 0·01 seconds.

The results obtained were comparable in accuracy to those obtained by the kinetheodolites. (Better results could of course be obtained by more complicated cameras and timing equipment.) Since this was so, and since the time taken to read the plate, identify the stars, and look up their coordinates, is much greater than that required to read a kinetheodolite record, very few exactly timed observations were made after April 1958. A few observations were made of *Sputnik 3* rocket, which have not been analysed, although as far as we know they were quite successful. Some attempts were made to obtain simultaneous radio and photographic records of *Sputnik 3*, but these ran into difficulties because the satellite was so faint; on the only occasion when a photograph was obtained, the timing apparatus failed.

The basic reason for our undertaking accurate photographic observations was that very few other observers were doing this, and it appeared that accurate knowledge of position was necessary in order to deduce the effect of the ionosphere on the radio signals. It has by now been conclusively shown that the best way to investigate ionospheric effects is not by simultaneous radio and photographic observations, but by simultaneous radio observations using two different known frequencies, preferably harmonically related, for which purpose it is not necessary to know the exact position of the satellite. Visual and photographic observations are, however, still very important, and we shall continue to make them from time to time.

8. Acknowledgments

We would like to thank those who have issued predictions for satellites, at Royal Aircraft Establishment, Farnborough, and Radio Research Station, Slough; also the Trials Department and the G.W. Department of R.A.E. for reading and analysing plates (especially Miss W. Lloyd), and the Director and Mr. J. Hewitt of Royal Radar Establishment, Malvern, for the use of the Zeiss plate reader. This paper is published by permission of the Director of Research, Marconi's Wireless Telegraph Co. Ltd.

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Manuscript first received by the Institution on 30th June 1961 and in final form on 2nd May 1962 (Paper No. 733).

Commonwealth Communications

THE COMMONWEALTH SATELLITE COMMUNICATIONS CONFERENCE

At the Commonwealth Conference on Satellite Communications, which met in London between 28th March and 13th April, representatives from Britain, Canada, Australia, New Zealand, India, Pakistan, Ceylon, Ghana, Nigeria, Sierra Leone, and the Federation of Rhodesia and Nyasaland participated in discussions which included the technical and economic aspects of satellite communications.† The Conference, which was of an exploratory character, concluded that satellite communication systems were technically feasible although a great deal of research and experimental work will be required before a satisfactory commercial system can be established; this may take some years. The Conference recommended that such work should continue to be actively pursued in Commonwealth countries.

Detailed consideration was given to the needs of Commonwealth communications and the advantage of a satellite system based on stabilized active satellites in equatorial orbit in the height range of 5000 to 10 000 nautical miles was clearly recognized.

The Conference forecast a promising future for the growth of telephone and telex communications and felt that a global satellite communications system could well become financially profitable within a few years of establishment. The possibilities of television relays, especially between countries with comparatively small time differentials, were also thought to be bright.

Satellite communications and submarine telephone cable systems were regarded as complementary and the projected submarine cable developments both by the Commonwealth and by other countries as well as research and development work in the submarine cable field should continue.

The Conference also considered the research and development work on satellite communications being undertaken in the United States of America and in Europe and decided to recommend that early discussions should take place with these countries in the hope that such co-operation would lead to a pooling of effort, and thereby achieve the best worldwide system of satellite communications. This recommendation is entirely in line with the United Nations General Assembly resolution of December 1961, which expressed the view that communication by means of satellites should be available to the nations of the world on a global and non-discriminatory basis.

FURTHER COMMONWEALTH CABLE LINK—AUSTRALIA TO SOUTH-EAST ASIA

A plan to complete by 1966 a Commonwealth telephone cable link between Australia and South-East Asia and Hong Kong has recently been announced.

The first part of the Commonwealth Pacific cable (COMPAC) linking Canada, Australia and New Zealand will be completed in July of this year. H.M.T.S. *Monarch* sailed last week to lay the cable between Sydney, New South Wales and Auckland, New Zealand. By the end of 1963, this same cable will have been continued via Fiji and Hawaii, right across the Pacific Ocean to Vancouver, to link up by microwave across Canada with the Commonwealth transatlantic cable (CANTAT) opened last December. A note on CANTAT was given in the April 1962 *Journal*.

In June 1961, representatives of Commonwealth countries who met in Kuala Lumpur, capital of the Federation of Malaya, recommended that a South-East Asia Commonwealth cable (SEACOM) should be constructed as soon as possible, following a route from Australia, via New Guinea, North Borneo, Singapore to the Federation of Malaya, with a spur from North Borneo to Hong Kong. This cable, like the Commonwealth transatlantic and Pacific cables, would employ British techniques, and would provide at least eighty telephone circuits. Its cost will be about £22½ million of which the United Kingdom share will be borne by Cable & Wireless Ltd. Detailed planning will be starting this summer. The recommendations of the Kuala Lumpur conference have been accepted by Britain, Canada, Australia, New Zealand, the Federation of Malaya and Singapore.

The SEACOM cable will bring marked improvements in regional communications between the Federation of Malaya, Singapore, North Borneo, Brunei, Sarawak, Hong Kong and New Guinea. Linked as it will be with the Pacific and Atlantic cables, SEACOM will also provide greatly improved long distance telephone and telex services for this region with Australia, New Zealand, Canada and the U.S.A., Britain and Europe. As time goes on these long distance facilities will no doubt be supplemented by satellite communications as is foreshadowed in the above report on the recent Communications Conference.

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† See *J. Brit.I.R.E.* **23**, p. 162, March 1962, and pp. 254–5, April 1962.

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Infra-red Applications in Navigation

By
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AND
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An abridgement of an informal paper read before the Radar and Navigational Aids Group on 15th November, 1961.

1. Introduction

The remarkable infra-red systems developed by the Germans during World War II fell largely into neglect in the post-war years, partly because radar had then been even more effective. In the last five years, infra-red systems have been coming back in powerful and versatile forms, this revival being due principally to the following facts:

(1) Infra-red detectors are now 100 to 1000 times faster than they were just after the war, and optical components for long wavelengths have become relatively cheap.

(2) Research on the atmospheric transmission of infra-red has shown that, in suitable spectral regions, attenuation is by no means as prohibitively high as was at one time believed.

(3) From the military point of view, modern targets are far more powerful sources of infra-red radiation, whilst they are frequently poorer radar targets.

(4) Countermeasures against infra-red systems are more difficult than for radar.

In this paper, some of the ways in which the new infra-red systems may be applied to navigation are briefly discussed.

2. Infra-red Communication Links

The use of modulated beams of light to convey messages is almost as old as the telephone itself: the earliest voice-modulated optical system on record is one made by A. C. Brown in 1878. Optical telephones were used by both sides in World War I, and again, very extensively and effectively, in World War II, but this did not lead to widespread civil use because the military equipments, designed to be rugged, and with little thought for cost, were large, clumsy and expensive in comparison with radiotelephones.

Recently, there has arisen a commercial and industrial interest in this useful invention, especially in America, where numerous equipments are marketed. Examples of their application are:

- ship-to-ship;
- ship-to-shore when entering or leaving harbour, or to communicate with Lloyd's stations;
- between relief vessels and lighthouses;
- between control tower and aeroplanes on runways;
- between control and pilots of carrier-based aircraft;
- in harbour surveys and oceanographic work;
- dockmasters to crane operators and tugs.

Fig. 1. A miniature photophone receiver using transistors and flash-lamp batteries.

Simple hand-held equipment can give excellent speech quality over ranges of up to one mile, while larger sets, mounted on tripods, can work over five miles or more. The use of lasers has recently made

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possible modulated light communication over immense ranges (earth to moon is quite practicable) and with provision for very many channels over a single beam.

3. Infra-red Radar

For ranges of a few miles, where the effects of atmospheric attenuation are not too severe, infra-red radar can offer definite advantages. The transmitter and receiver beamwidths can be made very narrow so that in ground-to-ground operation the infra-red system is less troubled with ground-clutter than is conventional radar. Side and rear lobes are absent, thus improving transmitter efficiency and increasing the intelligibility of the display. Moderate power requirements, and small size and weight, are additional merits.

Quite apart from lasers, which offer the possibility of infra-red radar systems far more efficient than any conventional equipment, there are various sources available for the transmitter. Recently, several devices have been described which can produce intense, accurately defined light pulses of the order of one to one hundredth microsecond in duration, and at variable high rate of pulse repetition. Infra-red detectors with response times down to a few millimicroseconds are available.

Reports from the U.S.A. show infra-red radar to have proved effective in airfield surveillance, and with the continuous rapid advances in infra-red technology the applications of such equipment are certain to become more general.

4. Noctovision Apparatus

Most of the wartime applications of infra-red to navigation were based upon the use of the image-converter to locate invisible infra-red beacons, used either for signalling purposes or to mark out approach channels or navigation hazards. That is to say, they were "passive" systems in which the object observed was self-luminous. Present-day navigational uses are mainly based upon "active" systems, in which an infra-red searchlight is employed to illuminate the area under surveillance. The lookout at sea rightly values the dark-adaption of his eyes, which enables him to detect a distant headland against the dim glow of the horizon, or to pick out the faint navigation lights of another vessel against a background of dark waters, and for this reason ordinary searchlights are to be avoided as causing unnecessary dazzle and inconvenience to other navigators.

The Japanese Maritime Safety Board recently established that infra-red noctovision equipment gave substantial improvements in visual range under conditions of haze, mist, or thin fog. The experimental results were essentially in agreement with those which Gebbie and his co-workers reported to the Royal Society in 1950. The Japanese experiments showed that an image-converter, employed in conjunction with a one kilowatt infra-red searchlight, could pick out small vessels at a range of about 1¼ nautical miles, in total visual darkness. Similar experiments have been made in the United States, and are now being carried out in Europe.

Less dramatic than the night-viewing equipment, but of no less importance, is the infra-red sextant. In this, an image-converter and an infra-red filter are fitted to a sextant, which now becomes capable of providing stellar sights in daylight, because the bright blue sky is black at infra-red wavelengths.

5. Infra-red Airborne Equipment

There are three distinct forms of infra-red equipment for aerial reconnaissance and navigation, operating on entirely different principles, and each possessing unique potentialities.

5.1. *Photographic Infra-red Reconnaissance*

In aerial photographic reconnaissance the most important things which record in markedly different ways on infra-red and on panchromatic plates are green vegetation and water. Infra-red changes the appearance of green vegetation from dark grey to white, whereas water changes in appearance from grey to intense black. Except over desert regions, there is a general increase in contrast with infra-red photographs.

5.2. *Passive Microwave Radiometry*

The detection of the millimetric radio waves which are emitted by all objects as a result of their thermal energy has formed the basis of several new navigation and reconnaissance systems. A suitable passive microwave system will give an observer clear pictures of the terrain over which he is flying, even through a considerable depth of cloud cover.

A microwave radiometer can readily distinguish between objects at the same temperature provided that their emissivity coefficients are different. The law of radiation which states that the total energy integrated over all wavelengths emitted by a surface is proportional to the fourth power of the absolute temperature, takes on a different form when very long wavelengths only are considered. The energy $E\lambda$ in M.K.S. units emitted at wavelength λ is given by:

$$E\lambda = \frac{2kT_b\varepsilon}{\lambda^2} \quad \text{watts metre}^{-2}\ \text{c/s}^{-1}\ \text{steradian}^{-1}$$

where T_b is the temperature of the surface, ε the emissivity, and k is Boltzmann's constant.

Consider an island at the same temperature as the sea, say 275° Absolute (2 deg C. above freezing point).

The land, with an emissivity of about 0·9 will radiate at an equivalent black-body temperature of 275 × 0·9 = 247·5° Absolute, whereas the sea, with an emissivity of about 0·4 will radiate at an effective temperature of 0·4 × 275 = 110° Absolute. In both cases, the reflected sky radiation should be added in to give an accurate figure, but it is not a large correction, and will be neglected here. In the present example, the sea, although at the same temperature as the island, appears to be 137 deg cooler. Because of this large difference in apparent temperature, it is possible to obtain clear pictures of land/water boundaries in total darkness and through heavy cloud cover.

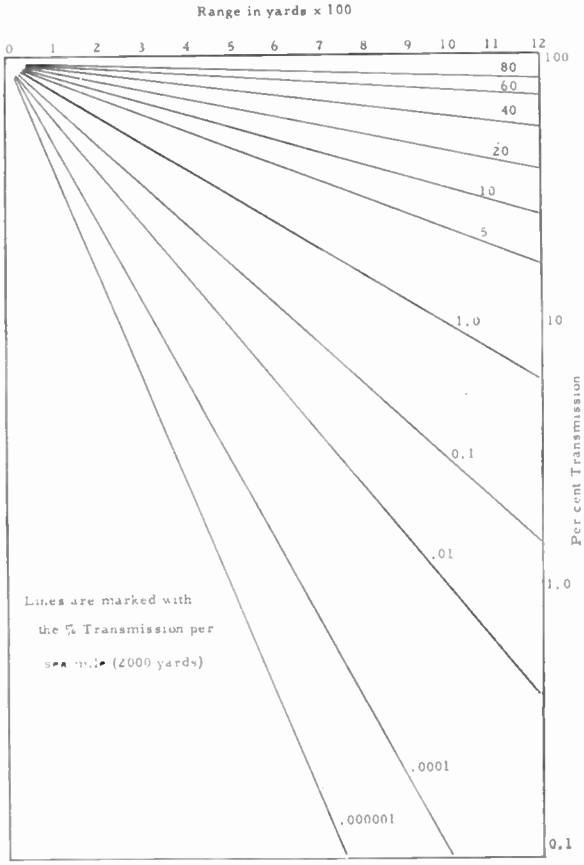


Fig. 2. Graphs of uniform attenuation.

5.3. *Far Infra-red Systems*

These make use of the thermal energy radiated by the ground in the spectral interval 4 to 14 microns, and although they have limited range in bad weather, they offer several advantages over both radar and photographic reconnaissance:

(1) Passive infra-red systems are not limited in information rate by echo propagation time, and have the advantage over photography that they can operate at night.

(2) Because of the improvement in aperture/wavelength ratio, far infra-red systems give much better angular resolution than either radar or passive microwave radiometry.

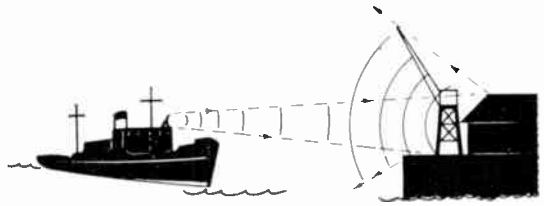
(3) Many objects of interest show up brightly in far infra-red pictures that would be invisible in passive microwave, radar, or photographic pictures. For example, a motor car with its engine running would be invisible to most radars (active or passive) from a height of two miles because of its small size, and would also be invisible in night photographs, but it would show up brilliantly in a far infra-red picture because of the heat radiated from the bonnet and exhaust pipe.

In a typical airborne infra-red scanner design the radiation from the ground is received by a 45 deg prismatic mirror with multiple faces which can be rotated at a high speed. For vertical scanning the axis of rotation is parallel to the aircraft heading line, but if the aircraft heading is not parallel to its ground track provision must be made to correct the attitude of the scanner accordingly.

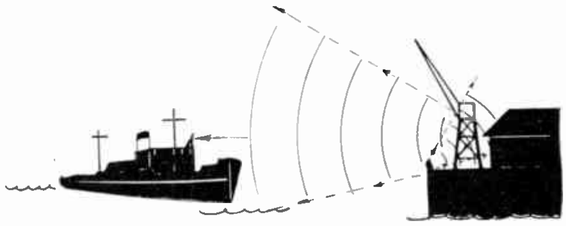
The instantaneous field of view is caused to scan through an angle at right angles to the ground track by means of the scanner mechanism: the motion of the aircraft ensures that successive scans cover successive strips of ground.

6. Marine Docking Aids

Some experiments carried out nearly 30 years ago by the U.S. Naval Research Department, using wavelengths of about 7 microns, showed marked increase in



(*a*) A fully-active infra-red docking system.



(*b*) Semi-active infra-red docking system.

Fig. 3.

the effective signalling range under conditions of moderate fog. The experiments were considered unsuccessful because ranges of several miles were not obtained. In contrast to this view, the docking of ships in thick weather would be greatly facilitated by any device which gave a clear visual range in excess of a few hundred feet. Figure 2 shows clearly that failure to penetrate a mile of fog is no proof that perfectly satisfactory results will not be obtained at more modest distances. It can be seen that as the percentage transmission for one sea mile falls from 100% to 1/100%, so does the transmission for 200 yds fall from 100% to 40%: a simple demonstration, which is independent of wavelength considerations.

Figure 3 (*a*) and (*b*) show docking systems which employ far infra-red scanners in combination with infra-red searchlights. It can be shown that, using conventional sources of a few kilowatts, ranges of two or three hundred yards can be obtained with the active system, and longer ranges with the semi-active system, under conditions of dense fog. Using lasers for the source of illumination, ranges of quarter-of-a-mile should be readily obtainable.

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Manuscript received by the Institution on 26th January 1962 (Contribution No. 53).

STORM-WARNING RADAR INSTALLATION IN AUSTRALIA

The first specially designed storm-warning surveillance radar to cover the inhabited areas of the north eastern coast of Australia threatened by tropical cyclones is shortly to be installed on Saddle Mountain 2000 feet above sea level, in North Queensland. It is expected to go into operational service in September. Designed and manufactured by Cossor Radar & Electronics, Ltd., Harlow, Essex, to a specification of the Australian Bureau of Meteorology, the radar has been ordered by the Australian Commonwealth Government.

Data from the radar on Saddle Mountain will be received via a microwave radio link at Cairns Airport, seven miles away. The radar, which has a nominal range of 240 miles, will enable meteorologists to observe the positions and tracks of storm centres, including cyclones, whose characteristic cloud patterns can be seen on a p.p.i. display. Iso-echo facilities will enable the densities of clouds and precipitation to be assessed.

The radar will operate in S band (10 cm) and will normally be controlled remotely from Cairns Airport via a v.h.f. link. The 800 kW transmitter operates at a fixed pulse repetition frequency of 300 pulses per second with a pulse width of 2 microseconds. The aerial consists of a fixed dipole mounted at the focus of an 8 ft diameter dish, giving a 2·6 deg beamwidth. Aerial elevation is adjustable from the Airport in 2 deg. steps between 0–16 deg. The azimuthal rotational information from the radar scanner is converted into a series of coded pulses which, after mixing with the video and transmitter trigger information, is decoded and applied to the remote p.p.i. The Saddle Mountain installation is completed by a monitor display and an automatically operated CO_2 fire prevention system.

The remote display at Cairns Airport consists of a 12 inch p.p.i. which incorporates iso-echo facilities. Four display ranges are available, the maximum being 240 miles, the shortest 30 miles. Other facilities include a north marker and a reflection plotter. This latter device enables information such as markers to be superimposed on the display without introducing parallax errors. Permanent records of display data can be obtained, either as single shots or time lapse sequences, by a magazine loaded 16 mm camera.

U.D.C. 621.396.946.004.6: 629.19

The Quest for Reliable Earth-Space Communications

By

HARRY T. HAYES†

Presented at the Convention on "Radio Techniques and Space Research" in Oxford on 5th–8th July 1961.

Summary: The paper deals with the practical aspects of the evolution of a space communication system from the initial design concept to the performance in orbit. Selected design problems encountered during the design and test phases of several space communication systems are discussed along with the remedial action taken to correct unforeseen deficiencies. The telemetry, tracking and command system used to collect the data from *Pioneer I*, *Explorer VI* and *Pioneer V* are used in the paper as examples of system evolution. The paper is concluded with a brief discussion of current work to improve the efficiency and reliability of space communication systems.

1. Introduction

From a superficial point of view the communication systems on *Pioneer I*, *Explorer VI*, and *Pioneer V* were all failures, in that in each case an element of the system ceased to operate while the spacecraft itself was still in a useful state. From the point of view of the total system complexities and the growth in mission objectives between these spacecraft, however, the systems were remarkably successful. From any point of view, the systems served extremely well as test beds for improvements in both the approach to space communications and the implementation of that approach. This paper will try to develop this last point, to sketch briefly some of the steps we have taken and the lessons we have learned in developing communications systems for these three spacecraft.

Pioneer I was the first American spacecraft to penetrate deeply into space. It reached an altitude of 70 700 miles on its two-day flight in August 1958 and remained in continuous communications with the Earth throughout its flight. Its contributions to the physics of space were very great; it discovered, for example, the ring current about the Earth and the limits of the Van Allen belts. Unfortunately, third-stage tip-off errors were too large to allow completion of the primary lunar objective and it was decided to attempt an earth orbit by firing the vernier rockets. During the second day of its flight, however, it failed to accept this command repeatedly transmitted from the Earth and as a consequence fell back into the atmosphere instead of entering permanent Earth orbit.

Explorer VI, in highly elliptical orbit about the Earth, was in continuous communication with the Earth and provided the first extensive mapping of the Van Allen zones throughout August and September 1959, but ceased transmitting much earlier than had been planned.

Pioneer V, in orbit about the sun, and certainly the most successful spacecraft ever launched, communicated for more than three months out to a range of 22·5 million miles, but it too ceased communications earlier than had been hoped.

Experience with this series of spacecraft, the *Able* series, which also included the partially successful *Pioneer II* and the ill-fated *Able-5*, has taught lessons and has required adaptations in six areas: temperature control, information filtering or pre-transmission data processing, digital techniques, system integration, automatic data handling, and what may be called attention to detail.

2. Thermal Control

It was, of course, recognized immediately in the *Able* programme that the temperature of the spacecraft needed to be controlled. The efficiency of many elements of a spacecraft varies with temperature; in some cases the additional weight of means for temperature control permits a net saving in over-all weight by optimizing the operating efficiencies of certain components. In any event, without temperature control of some sort, the side of a spacecraft facing the Sun would be so hot and the side away from the Sun so cold that no structure could long survive.

In practice the temperature of any surface in space is determined by its exposure to the sun and other radiating bodies, by its ratio of absorption to emittance of heat, and by its thermal connection to heat-generating portions of the spacecraft. The design of any space temperature control system is based upon using surfaces for both absorbing and for radiating heat. The external skin of *Pioneer I* was carefully designed to keep internal temperatures within the

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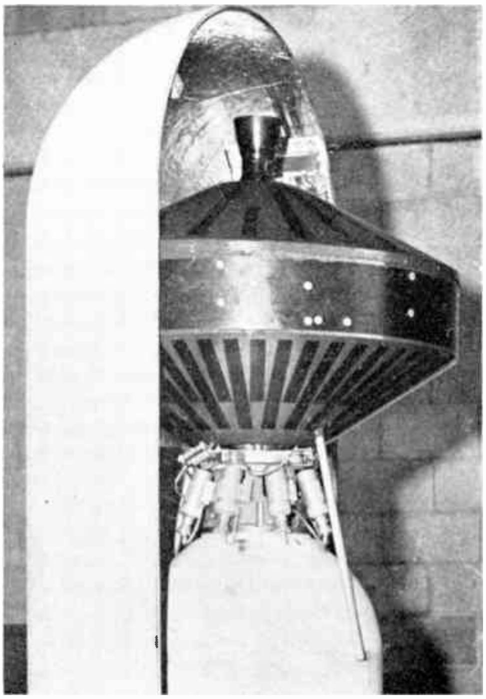

Fig. 1. *Pioneer I* just before launch with half of the nose fairing in place. Strips form temperature-control pattern.

proper range (see Fig. 1). Because launch was possible on any one of four consecutive days and because launch on each day would provide a slightly different attitude with respect to the sun for the spin-stabilized spacecraft, four distinct payload patterns were designed and prepared, with thermal characteristics precisely determined for each day's trajectory.

Unfortunately, during the launch of *Pioneer I* a slight tip-off angle, of less than 3 deg, was experienced in stage 3 separation. As a consequence *Pioneer I* was stabilized in inertial space along its spin axis at a slightly different angle from that for which the skin pattern had been designed. The mercury batteries which provided the power for the command circuits were therefore too cold to provide adequate power to close the command circuit relays, and the critical command to execute injection rocket firing, although properly received in the *Pioneer I* command system, could not be acted upon. In the design of *Pioneer I* the reliability of the power supply was carefully augmented by providing separate batteries for separate functions; clearly, however, insufficient attention had been given to the reliability of thermal control.

In addition to the obvious problem of eliminating tip-off angles at stage separation, the launch of *Pioneer I* served to draw attention to the necessity for adaptability in thermal control, despite the severe weight limitations which existed in the *Able* programme. Obviously at the expense of increased weight, an active thermal control system, highly adaptable to unexpected temperature situations, could have been incorporated. But to do this would have reduced weight available for scientific instrumentation to a point which would severely hamper the basic mission of the spacecraft. A passive system which would still rely on surface characteristics but would be

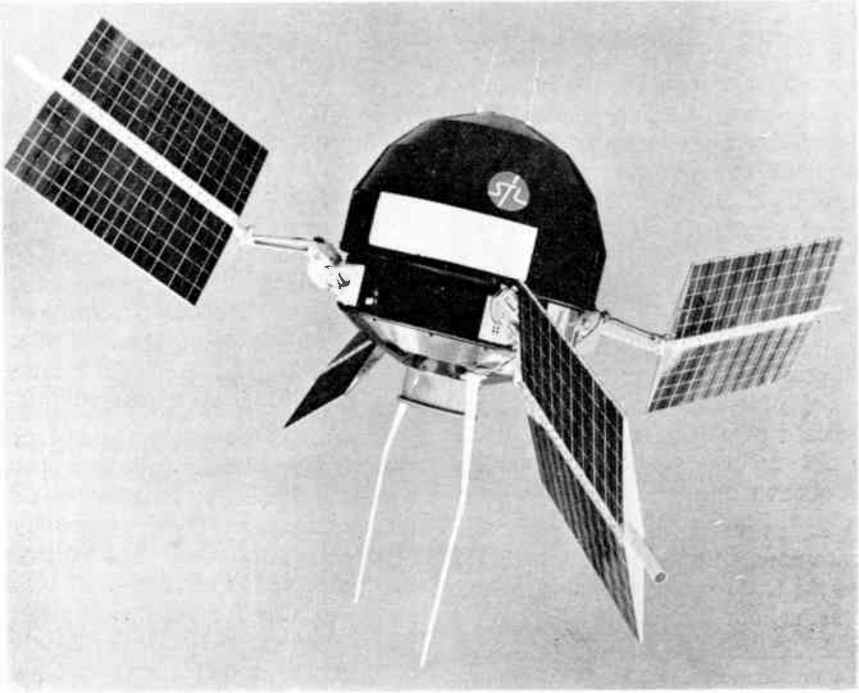

Fig. 2. *Explorer VI.*

considerably less sensitive to spacecraft attitude was needed. By the following year, when *Explorer VI* (Fig. 2) was launched, a systematic approach had been devised and tested, relying on heat sinks at the sites of heat generation, such as converters and transmitters, and an absorption-emittance pattern which was not critically sensitive to attitude.

Explorer VI also experienced a slight tip-off angle at separation (this time at third-stage-payload separation and stemming from the paddle-erection mechanism), but its temperature throughout its operational lifetime remained entirely within acceptable margins. The same approach to temperature control was also successfully applied to *Pioneer V*.

3. Information Filtering and Digitization

The data-handling system in *Pioneers I* and *II* consisted of an analogue f.m.-p.m. telemetry system accepting data from five and six experiments, respectively, and telemetering in real time. Output data from each of the experiments, in the form of a voltage, were fed to a sub-carrier oscillator. Output of the oscillator was an audio tone whose frequency depended on the input signal. The sub-carrier spectrum was summed into the multiplexing amplifier to provide a composite signal to modulate the transmitter.

The telemetry sub-carriers were recovered in the ground receiver and recorded on the magnetic tape. In addition, the sub-carriers were demodulated in a set of discriminators whose outputs were recorded on a pen recorder along with an indication of the received signal strength and timing marks. The tapes were then mailed to the central data processing facility in Los Angeles. There the magnetic tapes were replayed many times using discriminators with a variety of bandwidths. Many months were required to analyse the mass of data acquired during the two-day flight of *Pioneer I*.

In fact, it became quite apparent that had the operational life of *Pioneer I* been as long as hoped for the volume of data received would have completely saturated any data-handling facility on earth and the time lag between flight and recognition of results would have been prohibitive. Moreover, the manual techniques required for calibrating and interpreting analogue records were recognized as subject to human error.

The adoption of a digital telemetry system appeared highly desirable, then, in that it would permit the selective filtering or processing of data before transmission to the ground, and thus ease the data reduction problem and increase the reliability of the information by reducing the possibility of error from manual interpretation.

The strongest objection to the application of digital techniques to telemetry came from the physicists responsible for experiments. Each was opposed on the ground that he required as much information as possible; if quantity of the data necessitated filtering he wished to adapt the filtering technique to his specific goals after the raw measurements were on hand. A great deal of time, energy, and temper went into these conflicting views, before the design of the *Explorer VI* system was agreed upon. This telemetry system was a compromise incorporating both the former analogue system and a new digital system, both transmitting the same telemetry information. The greater weight of *Explorer VI* (143 lb versus the 85 lb of *Pioneer I*) permitted this redundancy. The scheme is illustrated in Fig. 3.

The digital system, called "Telebit", was designed to serve three purposes: first, to achieve pre-transmission data processing and thereby eliminate the flood of relatively useless information on the ground; second, to improve the efficiency of the communication system and thereby increase its information capacity; and third, to eliminate the large number of manual operations required between the time the data arrived on the ground and were delivered to the final user. The system was entirely successful on *Explorer VI*; its value was generally apparent only a few hours after launch, to the experimenter as well as the communication engineer.

A major advantage of Telebit, and one which further enhanced its value for *Pioneer V*, is its flexibility in adapting to range variations. When the transmitter is on, information can be sent at one of three different rates, reduced as range grows to keep the signal-to-noise level sufficiently high. In addition the Telebit system is adaptable to low transmitter duty cycles by accumulating and storing data during the intervals between transmissions. Averages can thus be obtained over the relatively long intervals between transmissions as well as over the relatively brief intervals that the transmitter is on.

The basic element of Telebit is the shifting accumulator, which can accept pulses characterizing the occurrence of events and total them or it can take the total number stored in the accumulator and, like a shift register, shift the information out to a modulator. Pre-transmission data processing results from the transformation of the occurrence of a sequence of events into a binary number representing the total of these events. The more frequently the total is read from the shifting accumulator the more nearly the system will convey the time at which an event occurred. At close range each shifting accumulator can be read frequently and thus localize in time the occurrence of an event. At greater distances the stored information must be transmitted less frequently and greater inherent filtering of the data results.

Experiments whose readings are analogue in nature,

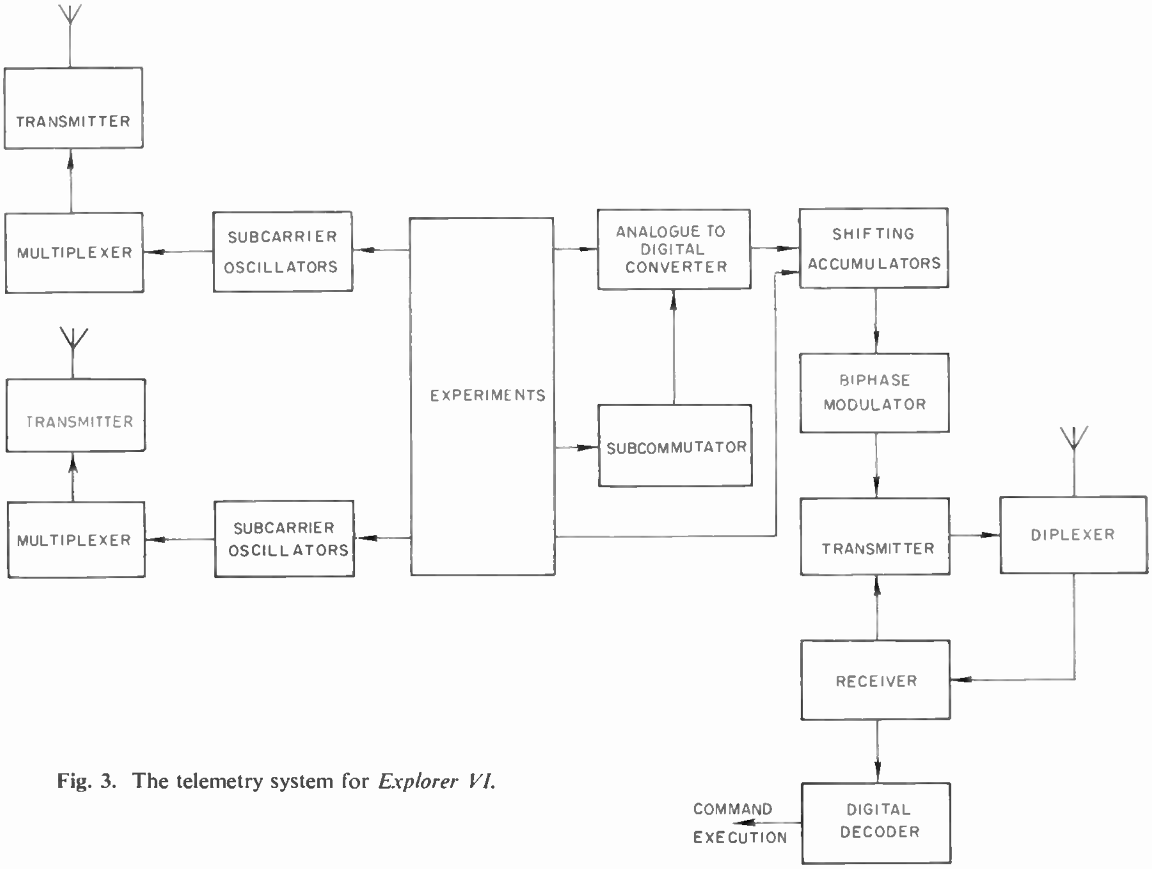

Fig. 3. The telemetry system for *Explorer VI.*

such as a magnetometer, are periodically sampled and converted to a number of pulses proportional to the analogue value. These pulses are fed to a shifting accumulator and then applied to the modulator.

An important factor in the development of space communications systems which was highlighted in this shift from analogue to digital techniques was the close co-ordination which must occur among the many disciplines represented in a space mission. An early example of this necessity was brought forth in the *Pioneer I* programme. The first design of *Pioneer I* treated the communication system as exclusively a telemetry device. Commands were to be executed by a timer in the spacecraft. Tracking accuracy permitted by elevation and azimuth readings on the telemetry carrier was conceived as sufficient. A prompt analysis by trajectory specialists, however, showed that even assuming completely successful launch the probability of mission success was only about 30% with this scheme. Greater tracking accuracy and more flexibility in command execution were needed to enhance the probability of success. Only three months before launch the communication system was expanded to include the additional capabilities of tracking by Doppler for velocity determination and of radio command from the ground.

In addition, it was discovered that the urge of experimenters to refine and improve their experiments was a dangerous one if it was allowed to continue too close to the scheduled launch date. Given a volume and weight limitation, the experimenter tends very naturally continuously to maximize the efficacy of his measurement. If at the same time he is not in close co-ordination with the designers of the communication equipment he is likely to increase his accuracy or bandwidth or duty cycle requirements beyond those that the system can accommodate.

System engineering, it was proved, is not a discipline that can be practised alone; it is a team effort. Every decision, every development must be promptly communicated to every member of the team and the team members in turn must promptly feed back their reactions. The quest for reliable communications systems must at the very minimum then include a smoothly functioning organization which guarantees prompt awareness to all of the progress of the elements of the design. A corollary to this lesson is that no member of the design and development team can operate within rigidly prescribed boundaries. The less that, for example, the mechanical engineer takes for granted concerning the chemistry of the rocket or the heat radiated by the transmitter the more successfully will his decisions concerning the spacecraft structure tend to lead to optimum total operation of the craft.

4. Integrated Communication System

A complete Earth-space communication system has three essential functions: telemetry, tracking, and command. The *Pioneer I* system encompassed all three of these goals, but tended to disassociate the functions by means of separate components. Moreover, the single transmitter, which handled both telemetry and tracking, performed one or the other of these functions, not both at once.

As shown in Fig. 4 this 300-mW transmitter was phase modulated by a sub-carrier spectrum applied through a multiplexing amplifier which summed the outputs of the various sub-carrier oscillators. Alternately the transmitter operated as the return link of a two-way Doppler system. Normally telemetry was transmitted, but when a command signal was received from the ground, crystal control and modulation were removed and telemetry ceased. Since there was no storage, information was thus lost during these periods.

As has been pointed out, a large amount of time was spent transmitting command signals to *Pioneer I* and thus there were large gaps in the telemetry record. The only way that this problem could be overcome in the *Pioneer I* system was to include another transmitter, to transmit telemetry continuously. For *Pioneer II*, therefore, a second, 100-mW telemetry transmitter was incorporated which would supply telemetry during tracking interruptions. The same sub-carrier complex was applied to both transmitters.

Clearly, however, the most economical use of the communication system was to integrate all three functions to permit multiple application of the individual components. The digital communication system therefore was designed as an integrated tracking, telemetry, and command system.

The *Pioneer V* transmitter, for example, was interconnected coherently with the receiver to form a transponder capable of providing both range and range rate information for tracking whenever it was operated. The carrier sent from the ground was accepted by the receiver, offset in frequency, and delivered to the transmitter for return to Earth. By this means very precise Doppler readings could be made by the ground stations. In this process as well the signal in the transmitter was phase modulated with a sub-carrier containing the time-multiplexed pulse-code-modulated output of the Telebit system. Bi-phase modulation was employed to impress the telemetry on the sub-carrier. By these means the same signal transmitted by *Pioneer V* was used both for telemetry and tracking (see Fig. 5).

At the same time the signal transmitted to *Pioneer V* to be transponded for Doppler readings was phase modulated with a sub-carrier to carry commands. Amplitude modulation of the sub-carrier with a coded train of pulses provided the required information to the command decoder in the spacecraft. The same two-way link between *Pioneer V* and the Earth was therefore used for all three communication functions.

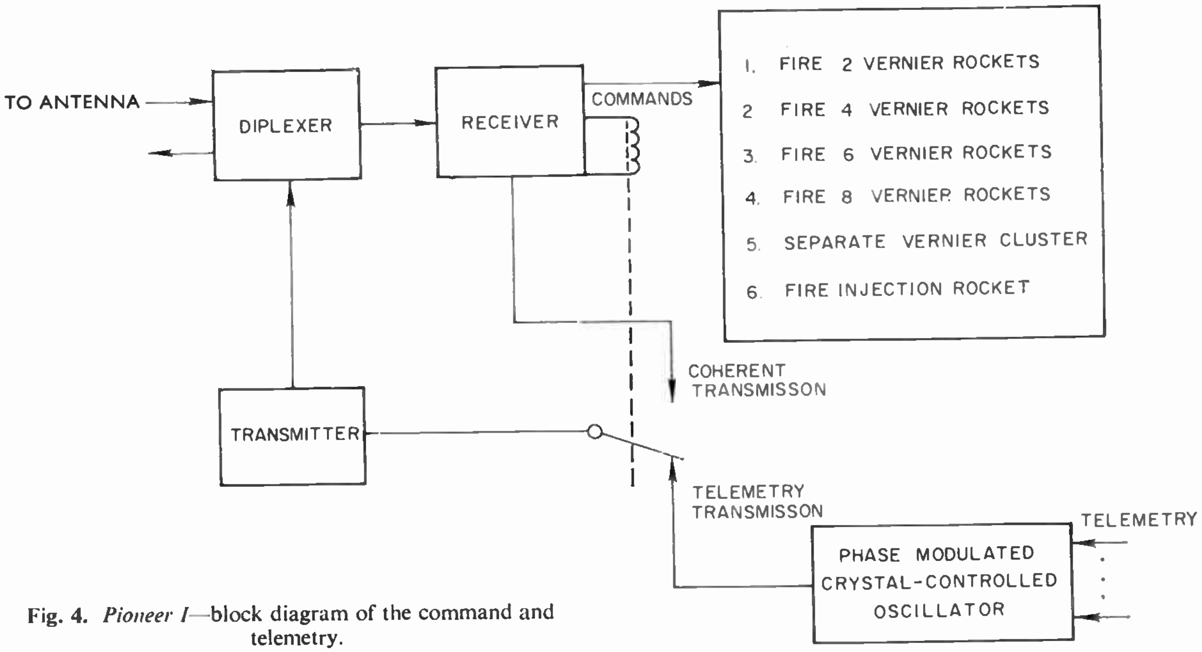

Fig. 4. *Pioneer I*—block diagram of the command and telemetry.

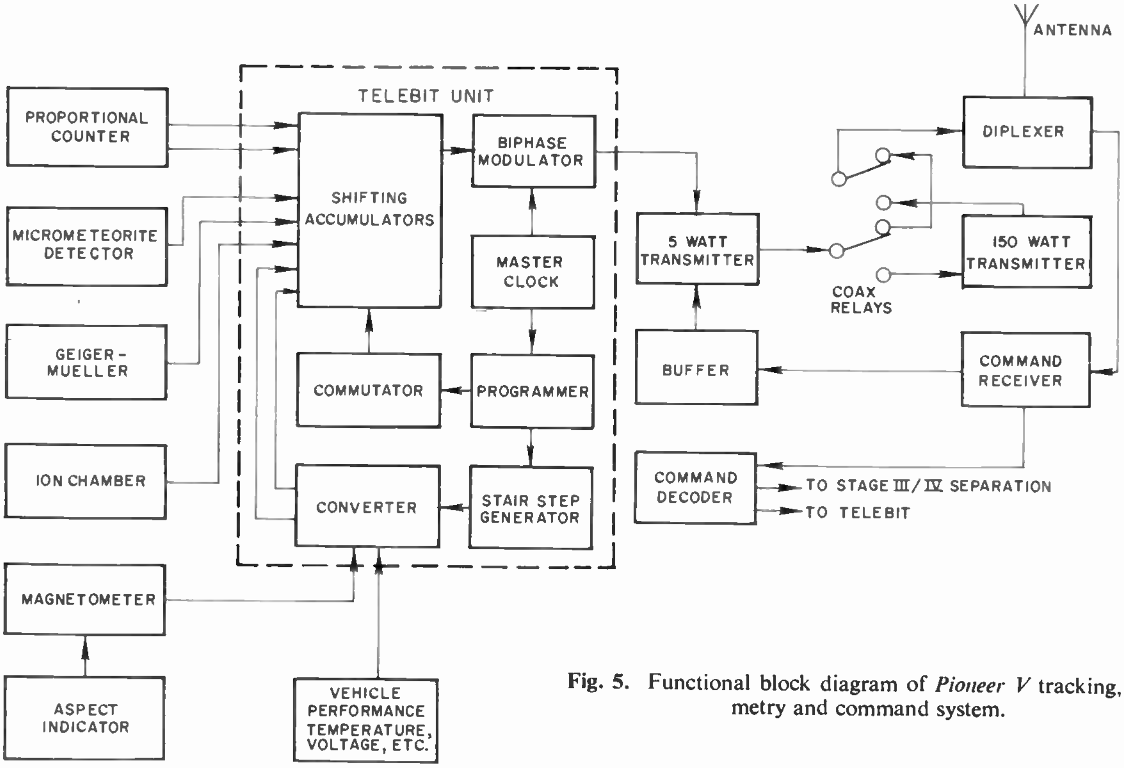

Fig. 5. Functional block diagram of *Pioneer V* tracking, telemetry and command system.

This integrated digital system permits the communication system to adapt itself to increasing range. As was illustrated in Fig. 5, two transmission powers are available on command, 5 watts or 150 watts. In addition, telemetry transmission was at the rate of 64, 8, or 1 bits/second, as commanded. Both the reduction in bit rate and the increase in power, however, are chosen at the expense of total telemetry transmitted. While battery capacity would permit lengthy transmissions at 5 watts, only about 6% of that time for a single transmission could take place at 150 watts before time had to be allotted to battery recharging by the solar cells. In fact, the increased range was obtained by means of a sharp reduction in total information received, as shown by the information content available in the six possible modes of operation (see Fig. 6).

Pioneer V was actually operated in only the first four of the six modes illustrated in Fig. 6. Decreasing capacity of the nickel-cadmium cells in holding a charge eventually made operation of the 150-watt amplifier impossible; the surge of power required to turn it on immediately activated the automatic under-voltage cut-off in the power supply. Thus the communications from *Pioneer V* ceased at a range of 19·5 million nautical miles when the 5-watt signal faded below ground acquisition sensitivity. Although only intermittent telemetry data were received beyond 12 million nautical miles, useful Doppler readings could be made so long as the ground equipment could lock on the *Pioneer V* signal.

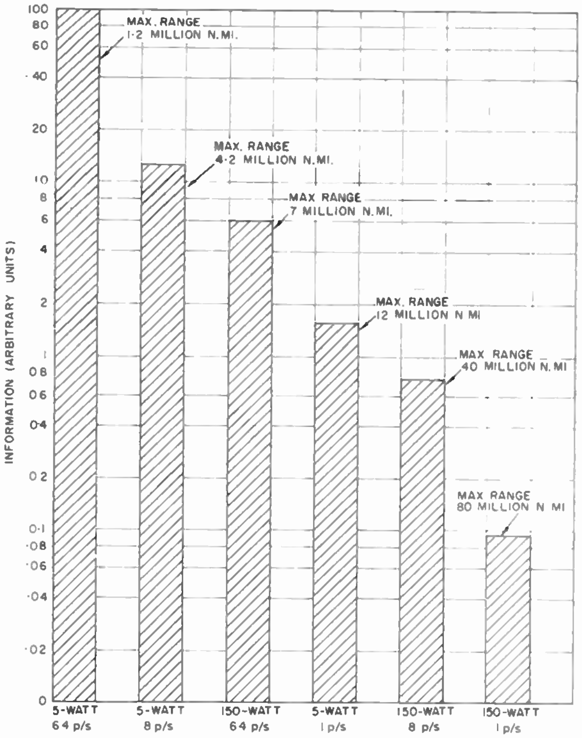

Fig. 6. Relative amounts of information telemetered in *Pioneer V* six modes of operation.

The command link, however, was in no way affected by the weakening battery capacity. The *Pioneer V* receiver, a transistorized double-conversion, phase-lock-loop unit, had power constantly provided by the solar cells. This link too was adaptable to increasing range. The receiver, operating continuously, functioned initially at a bandwidth of 250 c/s, and a threshold sensitivity of −130 dBm, sweeping a range of 40 kc/s with a period of 10 sec until it acquired a ground-transmitted carrier. On command from the ground which was executed on 16th April, when range was 3·3 million nautical miles, bandwidth was reduced to 40 c/s, thereby lowering threshold sensitivity to −138 dBm. The sweep period increased to 3 min. At this sensitivity, the Manchester 250-ft antenna transmitting at 10 kW could command out to ranges considerably beyond the 80 million nautical miles possible for telemetry reception.

5. Automatic Data Handling

As has been indicated one of the first lessons learned from our experience with the communication systems used in the *Able* programmes was the danger, both in accuracy and time consumption, created by the need for manual handling and reading of telemetry records. With the incorporation of digital techniques, however, automating the handling of data became quite practical.

The Telebit information when received at a ground station was demodulated in the receiver and applied directly to a teletype punch, as well as recorded on magnetic tape. The data were thus recorded directly in a form which permitted retransmission to the data collection centre without change. Where analogue records had to be interpreted by technicians at the ground station and put by them in teletype format to permit quick-look data to be sent to Los Angeles, the entire record could now be sent immediately. Only the magnetic tape record, as back-up, needed to be mailed.

Teletype data received in Los Angeles were transferred to IBM cards and then to an IBM 7090 computer. The computer was so programmed as to decommutate the time-multiplexed information and to apply calibration data from stored calibration curves to each experiment. Where appropriate, additional processing in the form of statistical analysis or correlation was performed in the computer.

Two manual steps remained in this process, however, the transfer of the record tape at the ground station to the teletype tape reader for transmission and the conversion to IBM punched cards in Los Angeles. For the *Able-5* launch several months later, both of these steps were automated. Amalgamation of the tape recorder and reader at the ground station permitted immediate transmission of the data as it was received. Equipment in Los Angeles received this letter code, printed it out as binary numbers for immediate reading by experimenters and payload engineers, and automatically fed it to the IBM 7090. Thus there was for this final *Able* spacecraft a direct, uninterrupted link between spacecraft and application on the ground of the telemetered data.

6. Attention to Detail

For others interested in creating and using a space communication system, some of the less grandiose but vital lessons learned on our *Able* programme may be of value. In sum the object lesson learned in these areas has been twofold: the key to attaining a reliable communication system for such individual spacecraft as the *Able* series is enthusiasm for the project among all persons working on it and, second, there is no detail in designing, constructing, or operating such a system that can be thought trivial.

With respect to this second point we have had to spend some sobering moments thinking about the fact that the power supply—conceived as the simplest and inherently the most reliable subsystem in the spacecraft—has been the weak link in all three, *Pioneer I*, *Explorer VI*, and *Pioneer V*. With the clarity of hindsight we can see that *Pioneer I* should have carried a greater number of batteries to offset any reduced efficiency encountered; *Pioneer II* in fact was so equipped. There was little that could have been done to prevent the high-energy proton damage to *Explorer VI*, but an extended vacuum test programme on storage batteries before the launch of *Pioneer V* would possibly have uncovered the weakness which caused the tiny ruptures and loss of electrolyte.

During the course of the programme many details which could have created major dangers to the spacecraft goals were fortunately recognized in time, although sometimes in the compressed schedule on which we worked they were diagnosed at a point uncomfortably close to launch time. For example, possible complete failure of the power supply for the scintillation counter in *Pioneer I* was averted but one day before launch. The potting compound in which this component was encased trapped many air bubbles around the 3000 volt leads and terminals in the power supply. On the day before launch it was recognized that in the hard vacuum these bubbles would doubtlessly leak and thereby establish a condition during launch in which an avalanche phenomenon could occur; as the pressure in the bubbles dropped, a critical point would be reached in which electrons from the high voltage source would be able to ionize the air molecules in a cascading fashion such that a short circuit would be developed through adjoining bubbles. Quick tests in a bell jar, simulating the dropping air pressure of launch, verified the suspicion. We spent all night before launch at Cape Canaveral gouging holes in bubbles in the compound and re-potting.

Another detail discovered shortly before the launch of *Explorer VI* was that the British punched hole code for TWX letters was different from the American. At the Manchester station a British converter was teletyping our telemetry letter code and in Los Angeles an American converter was printing it out. The letter code, which of course represented numbers rather than words, would be completely garbled. Not until we tested our land communication link did this fact present itself to our attention. It was a detail quickly resolved but had it not been discovered until after launch, quick-look examination of telemetered information would have been impossible. A similar problem not discovered until our land lines were tested was that the use of leased telephone lines for transmitting our 1024-c/s sub-carrier frequency from Hawaii to Los Angeles sent this signal through the telephone company's carrier system which when reconstructed at the receiving end included a frequency translation error which made our bit synchronization detection circuit inoperative. Telephone line accuracy is quite tolerable for voice communications but until decoding circuit changes were made it completely eliminated the possibility of reading the information in Los Angeles.

As a final example, we had not anticipated the difficulty we encountered in obtaining a high vacuum in testing our spacecraft in a vacuum chamber. As the chamber was evacuated, outgassing of components in the spacecraft tended to offset the evacuation provided by pumping. Where we had initially scheduled two days for a vacuum chamber test, we found that at least a week's soak in high vacuum was necessary before a vacuum of 10^{-5} or 10^{-6} mm of mercury could be maintained in the chamber.

Reliability is normally a statistical fact, arrived at by testing and examining a sufficient quantity of items to provide meaningful samples. The spacecraft in the *Able* series, however, were unique. Although each relied to some extent on experience from previous programmes, many components were created for the spacecraft, and the assemblage which was the spacecraft was entirely new. Formal inspection procedures, procurement standards, specifications and extensive operational test programmes served in significant measure to assist the quest for reliability in the absence of statistics, but it would have been impossible without enthusiasm among those doing the work. A case in point concerns relays used in the *Able-5* spacecraft. These were purchased from a manufacturer whose record for an excellent product had been spotless and whose enthusiasm for the *Able* mission was equal to ours. Labour trouble, however, brought about a situation in which the relays were assembled by workmen with no knowledge of their use, and that entire shipment had to be rejected.

7. The Future

Pioneer I carried five experiments and accepted six commands; *Explorer VI* carried nine experiments and accepted fourteen commands; *Pioneer V* carried six experiments and accepted eight commands. The increased magnitude of the communication problem for spacecraft of the immediate future is highlighted by comparing these requirements on the *Able* craft with those for the Orbiting Geophysical Observatory, which we are now developing. This satellite will carry up to 50 experiments and will accept about 200 separate commands.

These early spacecraft weighed in the neighbourhood of 100 lb (50 kg); the OGO satellite will be in the neighbourhood of 1000 lb (500 kg). Thus both the size of the spacecraft and the demands on the communication system have gone up by an order of magnitude. The need for careful use of every available pound remains about as stringent as before. The fact that the OGO and other immediately forthcoming spacecraft will be controlled in attitude in three dimensions, rather than the one-dimension spin stability of the *Able* series, allows us to use a directional antenna for the space-to-ground link and transmitter powers therefore need be no greater.

The reliability of space communication equipment is constantly being improved at both the component part and system levels. Improvement in the performance and application of solid-state components has increased the operating life of moderate power transmitters by an order of magnitude in the last two years. While the redundant interconnection of units is now being performed by external command, studies in computer techniques show promise in the areas of self-decision circuitry which will automatically interconnect working units and reject failed items. Advanced techniques have been developed for assembly, wiring, and packaging which allow lighter equipment with higher part densities and at the same time improve the reliability of the assembled unit.

The relatively near future should see large strides, then, in three areas of space communications: reliability, with lifetimes of years rather than months; range, with the 22·5-million mile record of *Pioneer V* bettered by 50 million miles; and information capacity, with 100-Mc/s bandwidths.

8. Acknowledgment

Credit for the manuscript preparation for this paper belongs to Mr. E. R. Spangler of STL without whose able assistance it would not have been completed.

Manuscript received by the Institution on 7th July 1961 (Publication delayed at author's request) (Paper No. 734).

U.D.C. 621.397

The Second International Television Symposium, Montreux

By C. B. BOVILL (*Member*)†

The Second International Television Symposium was held at Montreux between 20th April and 4th May 1962. The meeting was well supported and about 350 delegates from 25 countries attended. A total of 50 papers was read in the five days of the Symposium and there was also an exhibition of technical equipment.

Colour Television Progress in the U.S.A.

An interesting session was devoted to colour television and the meeting had the good fortune to be addressed by Dr. V. K. Zworykin who gave a report on the present state of colour television in the United States.

On the broadcast programme side, the National Broadcasting Corporation is planning to devote 2000 hours per year to colour in 1962–63 and more than half of the broadcasts will be during the evening and night time. This is an increase of 20% over last year. 87% of the 208 television stations of the N.B.C. are equipped for colour re-broadcast and 23 stations of the network can originate colour programmes. The Columbia and American Broadcasting Corporation networks have comparable facilities.

Dr. Zworykin stated that all manufacturers of colour television receivers in the U.S.A. employ the 70 deg shadow mask tube and that he was of the opinion that they would continue to do so for another year. They would then have available a 90 deg model, which is 6 inches shorter.

Mention was made of the new four tube camera which uses a 4½-inch image orthicon for the monochrome signal and three electrostatically focused and electrostatically deflected vidicons for the video information for the chrominance channel. The monochrome signal from this device is identical in quality to that from a black and white camera and defects due to misregister are completely absent. The colour pictures obtained with the new technique can be likened to four-colour printing and give better blacks and finer definition.

The image orthicon must evidently deliver the full channel information, but the vidicon channels only require a bandwidth of 2 Mc/s for the chrominance information; this makes registration requirements less exacting than with a conventional colour camera. Other improvements are easier adjustments, due to the electrostatic vidicons, and cooling of the targets which holds down the dark current and gives a better performance.

In the new camera, the light emerging from the objective is split, so that 20% is passed to the monochrome tube and the remainder is split further by dichroic mirrors and delivered to the three vidicons by optically similar paths. Changes in light transmission, due to polarization errors, and consequent distortions are avoided by this means. An *f*/8 aperture will give satisfactory results from a scene illumination of 250 foot candles. Further developments in hand will halve the light requirements. The camera is entirely transistorized, except for the deflection circuits. It was further stated that the four tube approach is better than the one monochrome, two colour channel arrangement, which derives the third colour signal by a process of signal subtraction, as it avoids the large signal errors inherent in that system.

Four Standard Television Receivers

H. L. Berkhout of Philips, Eindhoven, described the development of multi-standard television. If in Britain it is considered that 405/625 line double standard receivers are complex, some sympathy should be accorded to designers in countries such as Holland, Belgium, Italy, Eastern France, Switzerland and Germany, where four or five line standard receivers are required. Receivers for these countries require to operate on the standards shown in Table 1.

Table 1

Standard	Number of lines	Video modulation	Carrier spacing	Sound modulation
C.C.I.R.	625	negative	5·5 Mc/s	F.M.
Belgium (Flemish)	625	positive	5·5 Mc/s	A.M.
Belgium (French)	819	positive	5·5 Mc/s	A.M.
French (no equalizing pulses)	819	positive	11·15 Mc/s	A.M.

Some compromises were made in practical designs, because it is essential to keep costs within reasonable limits. Thus, with three of the standards requiring a bandwidth of about 4·75 Mc/s, and the French system requiring 9 Mc/s, 4·75 Mc/s is often accepted and the loss of definition is tolerable if good amplitude

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† Mr. Bovill represented the Institution at the Symposium. He is with Multisignals Ltd., London.

and group delay characteristics are designed into the circuits.

In current continental receivers, the standard switching is automatic when the channel is selected, a wheel with 12 cams being mounted on the spindle of the turret to carry out the line switching.

The turret tuner must be of the discontinuous type to enable some French channels which have the vision carrier on the high frequency side of the channel to be received. In this case, the local oscillator frequency must be lower than the signal frequency. This enables a common i.f. to be used. The tuners must also have sufficient bandwidth to accommodate the French channels. When using the C.C.I.R. standard, f.m. sound rejection is 20 times and when a.m. is used, as in the Belgian standard, rejection is 100 times.

The preferred method of arranging the detector and video amplifier for positive and negative modulation is to avoid switching in the detector circuit. The detector output is fed to the grid of the video amplifier, and the video signal is fed without a d.c. component to the c.r.t. in order to keep the d.c. setting constant. For negative modulation, the video signal is fed to the cathode of the c.r.t. and for positive modulation, it is fed into the grid. In both cases the brilliance control acts on the grid of the c.r.t. and noise clipping is fully effective for both types of modulation.

Automatic gain control presents special problems and these are elegantly dealt with. The a.g.c. information is taken from the cathode of the video amplifier to an a.g.c. valve and current only flows in it when the peaks of the signals are applied to its grid. The a.g.c. valve obtains its h.t. voltage from rectified fly-back impulses. This is applied to a resistance network, from which a negative voltage is obtained for control of the i.f. and r.f. stages.

The sound i.f. amplifier in a multi-standard receiver must operate on 33·4, 27·75 and 5·5 Mc/s. The sound i.f. is taken from a point between the tuner and the vision i.f. when a.m. is being received. The 5·5 Mc/s inter-carrier is taken from the detector circuit. Usually the a.m. and f.m. detectors are left connected to the i.f. amplifier and are switched to the a.f. stages.

Sync. separation presents no difficulties except in the case of the French standard which has a vertical sync. pulse which is different to the C.C.I.R. and other standards; the sync. pulse is passed through a differentiating network.

The line output stage is designed basically for the 819-line standard but when on 625 lines the deflection coils are connected to a lower tap. The disturbance of the 3rd harmonic tuning is corrected by switching in extra inductance, so that the load inductance of the transformer remains constant at all frequencies.

Direct Television Broadcasting from Space Satellites

In his paper entitled "Some Technical Factors Affecting the Feasibility of Direct Broadcasting from Satellites," Edgar Martin of the Broadcast Service of the U.S. Information Agency revealed a series of facts which put the immensity of the problem in its true perspective.

He assumed that a synchronous orbit satellite—that is one which is virtually stationary over a given point on the Earth's surface—would be used and also that for direct broadcasting, there would be no major changes in existing television standards, frequency allocations, domestic receiving equipment or aerials.

If the satellite is in a circular and equatorial orbit and is some 22 300 miles above the earth, a coverage of one-third of the Earth's surface is possible. Martin's computations for two sets of conditions are given in Tables 2 and 3. Table 2 is for partial visible coverage and it will be noted that an aerial beamwidth of 17·5 degrees is required to encompass the entire visible portion of the earth. At a frequency of 650 Mc/s, a suitable aerial is of reasonable dimensions, being 1·9 metres across the parabolic reflector. At 11 800 Mc/s it is very small.

In Table 3 the computations for maximum visible coverage are given. Here the problem becomes even more complicated and at 11 800 Mc/s, problems of heat dissipation in the small aerial would be encountered as the vision carrier power would be 74 kW and the sound carrier power 18·5 kW. From the computations given it is evident that h.f. broadcasting from satellites is unlikely, because of the size of the aerial and the very great power needed, also because of various effects from the ionosphere.

In the opinion of Martin, it would be difficult to use American Bands 8 (v.h.f.) or 9 (v.h.f.) for space broadcasts on account of existing frequency allocations, and he considered that frequency sharing would not be possible for the same reason. One cannot help feeling that for such a gigantic technical project, and the extraordinary value of broadcasts of the right kind from a satellite which would reach tens of millions of viewers in remote places, some effort to assign a satellite band should be made.

It was stated that the ground-based programme originator station should operate above the 6 Gc/s band.

Before a synchronous orbit television satellite can become a reality a number of formidable technical problems have to be solved. Among them are the development of high capacity power supplies, equipment that will operate without maintenance over a period of time consistent with economic justification,

Table 2

Synchronous Orbit Satellite at Slant Range of 42 000 km for Partial Visible Coverage.

Type of Service	A.M.	F.M.	T.V.	T.V.	T.V.
1. Frequency	18 Mc/s	100 Mc/s	70 Mc/s	650 Mc/s	11 800 Mc/s
2. Diameter of Parabolic Transmitting Aerial	40 m	40 m	40 m	6 m	0·371 m
3. Half Power Beamwidth of Transmitting Aerial	30·4 deg	5·5 deg	7·8 deg	6·73 deg	5·0 deg
4. Gain of Aerial	14·6 dB	29·4 dB	26·3 dB	30·2 dB	30·2 dB
5. Transmitter Power required for Parabolic Aerial	224 kW	0·0135 kW	2·75 kW	69·2 kW	6·03 kW
6. Primary Power required†	448 kW	0·027 kW	6·43 kW	17·3 kW	15·1 kW

Table 3

Synchronous Orbit Satellite at Slant Range of 42 000 km for Maximum Visible Coverage.

Type of Service	A.M.	F.M.	T.V.	T.V.	T.V.
1. Frequency	18 Mc/s	100 Mc/s	70 Mc/s	650 Mc/s	11 800 Mc/s
2. Diameter of Parabolic Aerial	40 m	12·5 m	17·9 m	1·9 m	0·106 m
3. Half Power Beamwidth of Transmitting Aerial	30·4 deg	17·5 deg	17·5 deg	17·5 deg	17·5 deg
4. Gain of Aerial	14·6 dB	19·3 dB	19·3 dB	19·3 dB	19·3 dB
5. Transmitter Power required for Parabolic Aerial	282 kW	0·138 kW	17·4 kW	427 kW	74 kW
6. Primary Power required†	564 kW	0·276 kW	43·5 kW	1·0675 MW	185 kW

† The primary power required is assumed to be twice the transmitter required power (based on an overall power efficiency of 50%). For the television transmissions the required audio power is assumed to be 25% of the required video power.

the dissipation of heat resulting from large power losses, and the development of station keeping systems.

If Martin's paper indicated the great possibilities of the future, that of R. P. Haviland of General Electric, Philadelphia, entitled "Early Possibilities of Space Broadcasting" dealt more with what could be done now. In his opinion low grade television broadcasts from synchronous orbit satellites would be possible now, as the techniques are sufficiently advanced but he stressed that one of the major difficulties is that of obtaining adequate power. Today, a satellite in synchronous orbit and transmitting a power of 350 watts on 550 Mc/s could only obtain enough power from solar silicon cells to give one hour's broadcasting per day. The broadcast would cover 2×10^8 sq. km, giving an average signal of 25 microvolts and it is probable that, to give satisfactory reception, domestic aerials would have to consist of stacked corner reflectors with high gain, pointing at the satellite.

Airborne Television Educational Broadcasts

In his paper on space television direct broadcasting, E. G. Martin questioned the necessity of a satellite transmitter. Examined closely, one sees that it is a very inefficient project, since even with a coverage of a third of the surface of the Earth, the greater part of the area must be sea. Also if any fault develops either with the satellite or its television equipment, it cannot be repaired and a vast sum of money will be wasted. There is also the continual fear of subject matter being fed into the recorder in the satellite by powers with a different outlook to the operators of the satellite, with consequent far-reaching results. It is for these reasons that the paper read by J. F. White of the National Educational Television and Radio Center, U.S.A., was of particular interest. He described the Mid-West programme for airborne television instruction (M.P.A.T.I.) which uses transmitters in high-flying aircraft to obtain half a million square miles' coverage from a single station, transmitting simultaneously two programmes.† In many ways this may be a far more practical, and certainly a far cheaper and more reliable method of obtaining large area coverage than a satellite. It can also be kept under full control. The aircraft at present fly at 23 000 ft and transmit on 819·25 and 843·25 Mc/s. A 24 ft retractable aerial is let out in flight and this is vertically stabilized to within ±2 deg by servo controls. Such aircraft flying a ten mile pattern over Purdue University, Indiana, cover ten major cities, 17 000 schools and a potential audience of more than seven million students.

The operating cost of the service is assessed at about six shillings per year per student and it is very doubtful if a satellite project could compete with this figure.

A Television Tape Recorder for Satellites

One of the schemes for television broadcasts for satellites is to record programmes on tape from signals transmitted from the ground and to re-transmit them from the satellite when it is over the territory to which the signals are destined.

To this end, special equipment has been developed by Ampex for the Goddard Space Flight Center. The Ampex device weighs 30 lb and at a tape speed of 1500 inches per second, gives a working bandwidth of 4 Mc/s.

The recorder will reproduce a 30 minutes television programme and occupies less than 1 cubic foot of space. In the recorder, the tape is driven in a helical path around a rotating drum and results in a recorded track diagonally across a 2-inch wide tape. Each head is in constant contact with the tape for more than 180 deg of its rotation. Two heads only are therefore required. The relationship between the heads of the recorded track must be very closely synchronized during play back. In the space recorder this is done by a metering capstan which controls the tape speed in relation to the rotational rate of the head.

During play back, a 240 pulses/second output from a head drum tachometer is compared with a 240 p/s signal placed on the tape during recording. Any difference in the two pulse rates is a tape speed error and a proportional correctional voltage is fed to the capstan motor. The head drum rotation rate is held constant by means of a closed digital servo loop. A 16 800 p/s output from a head drum tone generator is compared with a similar signal derived from a crystal controlled oscillator. A repetition rate difference represents a deviation from constant drum speed and a proportional corrective voltage is applied to the head drum motor.

Colour Television Transmission on a 1500 km Link

Dr. J. Müller of Fernmelde-Technisches Zentralamt, Darmstadt, gave an account of experimental colour transmissions over a television link between Rome, Berne and Darmstadt. These were made by co-operation between the German, Swiss and Italian P.T.T. and Radio Televisione Italiana.

The N.T.S.C. system was used for the tests and the object was to determine if the existing link networks were suitable for colour television. The route used was part of the Sicily-Scandinavia Eurovision network and it is particularly interesting to note that the microwave links were of different types and of German, Swiss and Italian origin. The total path length of the link was 1500 km (935 statute miles).

The equipment used at Rome, Berne and Darmstadt consisted of an N.T.S.C. modulator, a colour slide scanner, a colour bar generator and a test signal generator. The standard used was N.T.S.C. modified to the C.C.I.R. standard.

The measurements were carried out to international practice and test signals were as laid down in C.C.I.R. recommendation No. 267 for monochrome television. These tests were for field time waveform distortion or tilt, line frequency square wave for line time and short time waveform distortion (rise time, overshoot and tilt) and for the measurement of non-linear distortions.

The C.C.I.R. signal No. 3 was used for this purpose, but instead of the usual 1 Mc/s h.f. signal, the colour carrier was superimposed. A special receiver was used for the measurement of differential phase and the whole system including the N.T.S.C. coding were checked on signals from a colour bar generator with a vectorscope at the receiving end.

A black and white test chart was used for the resolution and gradation checks, whilst standard colour slides and a number of good colour slides were transmitted for subjective assessment of picture quality.

The test results can be summarized as follows:

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† Members will recall that a description of the original system—"Stratovision"—was read in London in 1949. (J. H. Battison, "American broadcasting", *J. Brit.I.R.E.*, 9, pp. 258–67, July 1949.)

To test the quality of the colour television signal, measurements were simultaneously carried out at Milan and Berne, along the link, and it was concluded that there seemed to be no law in the addition of transmission distortions, either in the case of linear or non-linear distortions and that the transmission deficiencies of the various video sections partially compensate one another. In spite of the four intermediate video points the measured values were well within the C.C.I.R. recommended tolerances.

The signal/noise ratio for continuous random noise at the receiving end in Darmstadt was 57 dB. The method of measuring this was to work without a video signal and to use the whole link as a noise generator, and to measure the voltage between 10 kc/s and 5 Mc/s. The objective measurements made it possible to conclude that the subject quality of the picture was satisfactory.

Subjective tests on picture quality, using 20 observers, gave very satisfactory results. Impairments in saturation and colour could not be perceived and only in critical portions of the picture could moiré interference be observed and then only if the viewer was too close to the screen. A large number of colour slides of pictures sent over the link were shown at the Symposium and bore out Dr. Müller's remarks concerning the good quality of the pictures received.

Dr. Müller's conclusion was that it would be possible to transmit N.T.S.C. colour pictures on existing international links but that it must not be forgotten that the tests only dealt with one part of the total link between the camera and the viewer in the home.

Points from Other Papers

V.H.F. Bands IV and V. Dr. H. Kösters of the Hamburg Radio Technical Institute reported that in general the average field strengths of Band IV and V transmitters is better than that anticipated in the C.C.I.R. propagation curves. Owing to the complex configuration of the lobes from v.h.f. aerials, particular care is necessary to prevent any movement due to wind, as this has been found to cause sharp fade-outs and signal strength variations even quite near the aerials.

Television Spectrum Economy. Professor Dr. F. Schröter, Ulm, is now working on development of a system which, by the use of a form of memory/display tube will entirely eliminate flicker and may lead to a reduction in overall bandwidth by a factor of 4.

Impressions of the Symposium

The Symposium was, on the whole, well organized and the lecture hall in the Montreux Palace Hotel was an ideal locale for the reading of the papers.

As some 10 papers per day were read, the time for discussion was very limited and it might be preferable in the future to reduce their number and to give more time for questions. It was an annoyance not to have preprints of the papers issued when they were read; it was specifically stated in the invitation issued by the Festival Organization that papers would be given to participants. Instead, a booklet containing summaries was handed out.

The international attendance was good, being dominated by Germany, with the number of British delegates the second largest. It was regrettable that only one British paper was read, by G. E. Partington of Marconi's. Certainly a description of some British achievements would have highlighted the value of the Symposium.

On the eve of the entry of the British into the Common Market, it is surely the time to bring to the attention of the world the extent of technical knowledge and industrial power of Britain. There were no British exhibits at Montreux. France, the U.S.A., Japan and Switzerland exhibited advanced equipment, probably worth over £200,000, and manned their stands with experts who could describe their equipment in more than one language.

APPLICANTS FOR ELECTION AND TRANSFER

The Membership Committee at its meeting on 31st May last recommended to the Council the election and transfer of 32 candidates to Corporate Membership of the Institution and the election and transfer of 38 candidates to Graduateship and Associateship. In accordance with Bye-Law 21, as adopted at the Special General Meeting held on 23rd May 1962, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communications from Corporate Members concerning these proposed elections must be addressed by letter to the Secretary within twenty-eight days after the publication of these details.

Transfer from Associate Member to Member

OSBORNE, Basil Whitworth, M.Sc. *Great Bookham, Surrey.*
REECE, Charles Norman William. *Edinburgh.*

Direct Election to Associate Member

ALLEN, Joseph, B.Sc. *Fareham, Hampshire.*
ARMSTRONG, Dennis Arthur. *Harlow, Essex.*
DUNKLEY, Albert, B.Sc. *Ashford, Middlesex.*
EDWARDS, Edwin James. *Sidcup, Kent.*
HEATH, Norman Arthur Kenneth. *Sidcup, Kent.*
HEMMING, George Thomas, B.Sc.(Eng.). *Birmingham.*
JANES, William Ernest. *Kuwait, Arabia.*
PEARCE, Major Geoffrey William Alan, R.E.M.E. *Malvern, Worcestershire.*
RANDALL, William Albert Douglas, B.Sc. *Chelmsford, Essex.*
SMITH, John William, B.Sc. *Brighton, Sussex.*
THOMAS, Francis Frederick, B.Sc. *Pinner, Middlesex.*

Transfer from Associate to Associate Member

JAMES, David Benjamin Garfield, B.Sc. *Swansea, Glamorgan.*

Transfer from Graduate to Associate Member

BOWEN, Kenneth. *King's Lynn, Norfolk.*
BRISTOW, Hubert Ronald. *Barnet, Herts.*
BRITTAIN, Austin Furey, B.Sc.(Eng.). *Kuala Lumpur, Malaya.*
CHESTERS, John Lhind. *Liverpool.*
DAVEY, Norman Charles. *Sanderstead, Surrey.*
FAIRCHILD, Victor. *Stevenage, Hertfordshire.*
HAMMOND, Bruce James. *Stevenage, Hertfordshire.*
HOWES, Bentley Arthur. *Thornton Heath, Surrey.*
LE WARNE, John Arthur. *Maidenhead, Berkshire.*
MONTGOMERY, John. *Thatcham, Berkshire.*
PAYNE, Michael Roy. *Hayes, Middlesex.*
PRABHAKARA-RAO, Captain Gadiyar. *Mhow (M.P.), India.*
PRICE, Peter John, B.Sc. *Camberley, Surrey.*
SAYWELL, John Stephen. *Elizabeth East, South Australia.*
SCHOLFIELD, Derek MacGarvey. *Blackburn, Lancashire.*
WILLIAMSON, John Morrison. *Chelmsford, Essex.*

Transfer from Student to Associate Member

GOODCHILD, John Lionel. *Goring-on-Thames, Oxfordshire.*
SHARP, Robert William David. *Cranham, Essex.*

Direct Election to Associate

CAMPBELL, Charles Frederick. *Brampton, Cumberland.*
FRENCH, Harry. *Sandown, Isle of Wight.*
GLENN, Neville Roland St. John. *Ryde, Isle of Wight.*

Transfer from Student to Associate

BLOWE, Peter Ryder. *Nairobi, Kenya.*
TREVELYAN, Bernard. *West Molesey, Surrey.*
VELATE, Anthony Spencer. *London, N.W.7.*

Direct Election to Graduate

BODGER, Captain William Robert T., R. Sigs. *Catterick Camp, Yorkshire.*
CHADDA, Vijay Kumar. *London, S.W.19.*
CHAPMAN, Alton Victor. *London, N.6.*
DALLY, Captain Peter Attwood, R. Sigs. *Catterick Camp, Yorkshire.*
DUTHIE, Anthony. *London, S.E.3.*
FAGAN, Keith Eric. *Great Malvern, Worcestershire.*
HARRISON-JONES, Andrew. *Barmby Moor, Yorkshire.*
KING, John Stanley. *Southampton, Hampshire.*
McKENZIE, Pilot Officer Ian, R.A.F. *Benson, Oxfordshire.*
OATEY, Flight-Lieutenant Alan Henry, R.A.F. *B.F.P.O. 69.*
*PADMANABHAN, Rajagopalachari. *Bangalore, South India.*
POWELL, David Victor. *Plymouth, Devon.*
RICHARDS, William Milner. *Weston-super-Mare, Somerset.*
SIMPSON, Leonard. *Bolton, Lancashire.*
STANSBY, Anthony George, B.A. *Sale, Cheshire.*
TALBOT, Captain Peter Allard, R. Sigs. *Catterick Camp, Yorkshire.*
TAYLOR, David John. *North Malvern, Worcestershire.*
TEAGUE, Barry Russell, B.Sc. *Liverpool.*
TILBURY, Brian Robert. *Hounslow, Middlesex.*
WHITCOMB, Gordon Peter. *Malvern, Worcestershire.*
WONG, Liang Keen, B.Sc.(Eng.). *Singapore.*
WORGER, Stanley. *Edgware, Middlesex.*

Transfer from Student to Graduate

AGASS, Benjamin Edward. *Basingstoke, Hampshire.*
CHARAN SINGH, Captain, I. Sigs. *Delhi, India.*
CLARKE, John Reginald. *Wantage, Berkshire.*
DIXON, Donald Charles Stanley. *St. Austell, Cornwall.*
HARDCASTLE, John Andrew. *Liverpool.*
IYER, Rama Padmanabha. *Delhi, India.*
LONGHURST, Charles Edward. *Redhill, Surrey.*
MADAN, Rusi Sorabji, B.Sc. *Surat, India.*
PERRY, John Francis. *Marlborough, Wiltshire.*
YASIN, Lieutenant Mohammad. *Rawalpindi, West Pakistan.*

STUDENTSHIP REGISTRATIONS

The following students were registered on the 3rd and 31st May.

MADHAVA ACHARYA, A., M.Sc. *Mysore State, India.*
MILLS, Norman F. *Feltham, Middlesex.*
MENEZES, Crisan Michael, *Bombay.*
MURLEY, Alfred R. *Portsmouth, Hampshire.*
NASSER, Mohamed H. M. *Mombasa, Kenya.*
OBI, Michael Abiodun. *Lagos, Nigeria.*
PATEL, Ramanbhai G. *Southsea, Hampshire.*
PITTAWAY, Neil G. *Coulsdon, Surrey.*
POTTER, Brian Winston. *Plymouth.*
PRASADA-RAO, Durga N., M.Sc. *Poona.*
RAMACHANDRA-IYER, Rama Iyer. *Secunderabad, India.*
RAMACHANDRAN, Sekharipuram Ramaswamy, M.Sc. *Ernakulam, India.*
RAY, Amalendu. *Calcutta.*
RESPONDEK, Joseph F. *Coventry, Warwicks.*
SAIN VERMA, K. *Sahapanpur, India.*
SAINI, Swarn Singh. *Bombay.*
SEN, Naresh C., B.Sc. *Levallois, Seine, France.*
SILVA, Liyanaralalage M. P. *Mt. Lavinia, Ceylon.*
SOLOMON, Joseph E. *London, S.E.22.*
SREEKUMARAN, Moosathu O. N., B.Sc. *Dehra Dun, India.*
TILY, Geoffrey John. *King's Langley, Herts.*
TOOGOOD, Alan E. *Stanford-Le-Hope, Essex.*
VASEER, Prithvi Pal S. *Bombay.*
WARNER, David J. *Hornchurch, Essex.*
WATSON, Pilot Officer Peter Axel, R.A.F. *Timsgarry, Isle of Lewis.*

AMA, Efiong Daniel. *Lagos, Nigeria.*
ANOKWULU, John Izunwanne M. *Lagos.*
AYOADE, Liyide Ade. *London, W.6.*
BANDYOPADHAYAY, Salil Kumar B., M.Sc., B.Sc. *Calcutta.*
BERRY, John A. L. *Farnborough, Hampshire.*
BROOKSBANK, David H., B.Sc. *London, N.8.*
CHRISTIANSON, Alan H. *London, S.W.3.*
COWIE, Hector. *Thurso, Caithness.*
DOLBEY, Paul. *Ashford, Middlesex.*
DORAI RAJ, G. *Erode, South India.*
ELOBUIKE, Joseph C. *Lagos.*
EYO, Christopher E. A. *Lagos.*
FERNANDES, Albert J. F. *Nairobi.*
GOODEY, Ernest B. *Carrickfergus, N. Ireland.*
HAFEEZ, Syed A., B.Sc. *London, S.E.24.*
HALL, John L. *Calne, Wiltshire.*
HARBHAJAN, Singh, B.A. *Southall, Middlesex.*
HAYWARD, Lieutenant Nicholas Samuel John, R.E.M.E. *Gosport, Hampshire.*
HICKLING, Ian Derek K. *Ilford, Essex.*
HOOPER, Michael Frank. *Basingstoke.*
HOWARTH, Edward. *Bolton, Lancashire.*
IFTIKHAR, Captain, B.A., B.Sc. *Rawalpindi.*
JAYAWARDHANA, S. C. *Panadura, Ceylon.*
JONES, Robert A. *Thurso, Caithness.*
KING, William. *Adelaide, S. Australia.*
KOMOLAFE, Michael Oludare. *Lagos.*
LEONG ENG FOON. *Singapore.*
LEYSHON, Michael J. *London, E.C.2.*
LIEBENBERG, David S. *Chingola, Rhodesia.*
*MACARTNEY, Robert A. *Taranaki, New Zealand.*
MANGAT, Parmindar Singh, B.Sc.(Eng.). *Nairobi.*
MARKWELL, John E. *Parcllyn, Cardigan.*
MENGHANEY, Mengho O., B.Sc. *New Delhi.*
MILLS, Gordon Evelyn. *B.F.P.O. 10.*
MURRAY, Wayne. *Waratah, Australia.*
OLAMIYAN, Emmanuel B. *Lagos.*
OLLEY, Abraham T. *London, S.E.19.*
OSAKWE, Joseph C. I. *Lagos.*
PALK, Colin John. *Droitwich.*
PITCHER, Desmond H. *Liverpool.*
PRICE, Gareth C. *Abergavenny, Monmouthshire.*
RAMALINGAM, P., M.Sc., B.Sc. *Tirunelveli Town, India.*
RIGLEY, William A. *Kanpur, India.*
SMITH, Kenneth Roland. *Cheltenham.*
TALKAR, Kenneth J., M.Sc., B.Sc. *Salisbury.*
TARRANT, James E. *Thornton Heath.*
THOM, David A. *London, S.E.10.*
WATERLOW, Richard J. *London, E.17.*
WATSON, Derek A. *Bedford, Nova Scotia.*

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* Reinstatements

U.D.C. 621.382.3: 621.039

The Impact of Transistors on the Design of Reactor Instruments

By

E. P. FOWLER, M.A.†

Presented at the Symposium on "Electronic Instrumentation for Nuclear Power Stations" in London on 29th September 1961.

Summary: The requirements of reactor instruments demand an unusual emphasis on the philosophy of fail to safety, guaranteed power supplies in all circumstances and reliability over long periods of operation. The special advantages of transistors in the development of these instruments are simplicity of circuit and economy of power required. As a result, a greater emphasis can be placed on a.c. or pulse operation of circuits which, although inherently more complex, can be made much safer than d.c. operation.

New instruments designed for the U.K.A.E.A. take their power from a d.c. supply of 50 V centre tapped or from the a.c. mains which considerably eases the provision of stand-by facilities. A description is given of a logarithmic amplifier and period meter with a wide range, fast response and no period overshoot which typifies the approach. A potentiometric recorder and pulse counting channel are briefly mentioned.

1. Introduction

It is widely appreciated that the safety problems surrounding the operation of nuclear power plants demand that the protection system should always operate when a genuine fault exists on the plant. This factor creates a strong emphasis on the following features in the design of reactor instruments:

(1) The fail-to-safety philosophy.

(2) The necessity for continued functioning under some exceptional fault conditions; notably the failure of normal methods of power supply.

(3) Continuous reliability over a long period.

The main points of a fail-safe philosophy are worth noting as they must be kept constantly in mind during the early design stage of an instrument as well as being acted upon during the appraisal of a design. In certain first line protection instruments such as shut-down channels which give a reactor trip on high neutron flux, the fail to safety property is paramount and decides the whole line of approach; in all instruments the fail-safe requirement will colour the design. The following details illustrate the problem:

(a) Any credible failure in an instrument or group of instruments should result in a situation which is safer than that immediately before the failure. Thus an indicating meter should read higher and an alarm or trip circuit should give its alarm or trip in the event of any internal failure.

(b) On safety circuits containing relays, the initiation of alarm shall be by de-energizing the relays by breaking the circuit. This is a much more likely accidental fault than a short circuit and will also give complete protection against all supply failures.

(c) The operation of a trip must not be inhibited by gross overload.

(d) As the presence of neutron flux is not apparent to the operator it is essential to show that any measuring channel is working properly. To this end, no instrument should be relied on for protection unless it is already "on scale".

(e) The use of alternating or pulse signals is preferable to direct current signals because of the greater discrimination possible against spurious pick-up and faults.

(f) Stand-by type protection circuits are not desirable as it is very difficult to show that the protection circuit itself has not failed at some time previous to that when the "protected" fault occurs.

(g) Care must be taken to avoid the possibility of "chain-reaction" faults.

Summarizing, a reactor instrument requires a wider range and greater reliability than most industrial instruments, the ability to work from stand-by supplies and the greatest amount of fail-safety possible.

2. Special Advantages of Transistors

When transistors first became available, the device was seen as a boon by those requiring space and weight saving particularly where the power supplies had also

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† U.K. Atomic Energy Authority, Atomic Energy Establishment, Winfrith, near Dorchester, Dorset.

to be carried. The characteristics such as low voltage operation and low power requirement, also pointed to a long life in these devices. Early junction transistors suffered from a very low cut-off frequency so that it was seen to be very unlikely that a full transistor-built replacement could be made any better than, if as good as, existing valve equipment. A start was made on health and monitoring applications and several useful instruments have been produced.

Now that reasonably priced transistors with very much higher cut-off frequencies are available and more is known about the special requirements of transistor circuits, it is possible to make a new instrument with a performance comparable with the best valve equipment. Transistor characteristics are improving at such a rate that it is reasonable to predict that performance will far outclass the best obtainable with valve equipment in the next few years. Some valves are still required, notably the electrometer triode but great attention is being paid to the improvement in reliability of these special elements in an otherwise all-transistor reactor instrument.

Some of the improvements to be expected are greater reliability of the active elements (transistors should be more reliable than valves) together with greater reliability of the associated resistors and capacitors. Simpler and less bulky circuits result in less inter-connections and more reliable channels while the lower voltages and impedances make insulation problems less severe and ease the stand-by supply problems. While experience shows that the under-rating of associated components considerably improves their life, there are insufficient data yet on the practical reliability of the transistors themselves. Improved production techniques should nullify some of the adverse criticism that has existed recently on the life that has been found for transistors in early equipments.

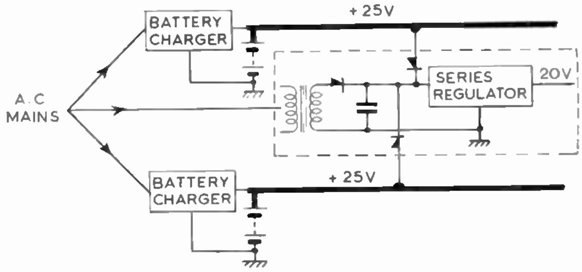

Fig. 1. Principle of two battery supply, showing positive line only.

As a transistor is more flexible in its circuit requirements than a valve, very much more direct coupling is possible and desirable. This, together with the judicious use of complementary transistors can provide an elegant solution of a circuit design problem. The problem of stand-by supplies requires special mention as the normal involuntary change to a stand-by generator is very liable to introduce a switching surge into an a.c. supply system. The use of d.c. stand-by supplies obviates this by the use of diode connections to each instrument. These diodes ensure that power is taken from the highest d.c. potential whether it be a.c. rectified or straight from the battery (Fig. 1).

In this block diagram, the heavy lines at the top and bottom represent busbars directly connected to the batteries. Each instrument, represented by the dotted line box, is coupled to the two independent battery supplies and can be connected to the a.c. mains. Under all conditions the instrument takes its power from the highest voltage available which would normally be the rectified mains supply. In the event of failure of the mains or of one of the batteries, power is still available from the other battery without any switching.

Fig. 2. Logarithmic ratemeter, A.E.R.E. type 1598A.

Mention should be made that in such a stand-by circuit, it is essential that no failure in the battery charging unit shall result in a short circuit being put on the stand-by battery.

If it is desired to run without mains connection to each unit, it is practicable and no less safe to take power normally from one or both of the battery lines. In this case the battery chargers must be able to supply the whole load and the full charge current to a discharged battery.

3. Early Instruments

It was mentioned earlier that the first transistor instruments were used for health monitoring applications. One such instrument (Fig. 2) has a logarithmically-scaled ratemeter and is used with a Geiger counter for measuring gamma and beta radiation levels. A count rate of $\frac{1}{2}$ to 500 per second is covered on a logarithmic scale with three calibrated trip or alarm circuits. The ratemeter uses a total of fourteen transistors of which only two are in the measuring circuit.

The transistors used in this equipment were slow and had a low thermal dissipation. To utilize them

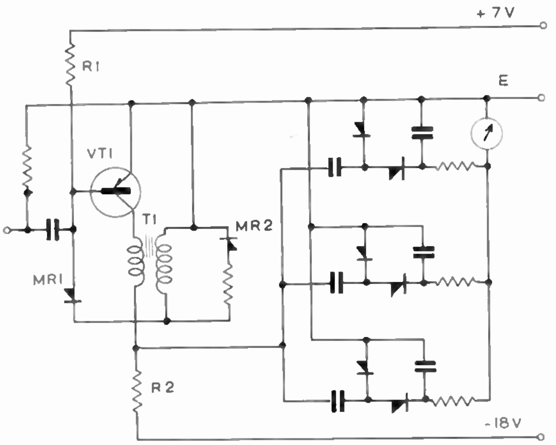

Fig. 3. Blocking oscillator circuit for logarithmic ratemeter.

with greatest efficiency a large number of the circuits use the transistor as a switch. Thus the head amplifier is in fact a monostable series blocking oscillator circuit while the drive to the ratemeter pumps is a similar circuit using a power transistor (Fig. 3). In the quiescent condition the transistor is cut off and the bias current flowing through MR1 holds its base at approximately + 0·2 V. A negative pulse at the input will first take all the bias current and then turn on the transistor. The transformer action of T1 then enables the transistor to hold itself hard on (bottomed) by supplying the bias and base current through MR1. As the base emitter voltage is only − 0·3 V and the transformer has a small step-up ratio, the primary volt drop is negligible and the whole of the supply voltage is seen across the load resistor, R2. The load resistor defines the transformer primary current and this is divided between the magnetizing current and that supplied to hold the transistor on through the secondary winding. As the magnetizing current rises linearly there comes a time when insufficient current is available to hold the transistors on and the process reverses. On reversal the transformer is reset by discharge through MR2.

At a top frequency of 500 counts/second, the circuit dead time needs to be as low as 200 μs for 10% count rate loss from random counts. This requires a pulse width of 100 μs to allow 100 μs for recovery afterwards. At very low count rates the loading of the ratemeter pumps is very great and difficulty might be experienced in charging the pumps fully in 100 μs. However, one attractive characteristic of the series blocking oscillator is that the pulse length is increased by extra load so that the pumps are fully filled, even at very low count rates, by a pulse length extended to 400 μs without degrading the performance at high count rates.

A similar blocking oscillator is used in the trip circuits giving a trip which is very economical in its use of transistors. This circuit has now been used in many different equipments because of its high fail-safe property with economy in components. Several of these units have been in service for two years with no fault at all yet recorded.

A second amplifier has had an unusual career. Originally developed as a trip amplifier to guard against radiation danger from a reactor loop experiment, the first twelve instruments were not immediately needed and were put on life test. The circuit comprised an electrometer valve followed by a three-stage balanced transistor amplifier. In fifteen months test on twelve units, only three faults were recorded; one a dry joint on a plug connection and the other two due to fall-off of emission on the electrometer valve. This circuit was also used as the basis of two other instruments some of which have now been in service for a year. With only three installed instruments some six faults were recorded in six months, half of which were attributable to a transient short circuit on one supply rail, while the rest could have been due to overheating of a transistor on wiring in.

Analysis of the results available leads to the conclusion that accidental shorting during test and maintenance cannot be discounted and instruments must be designed to accept this. Figures 4 and 5 show the modification required in this light in an otherwise

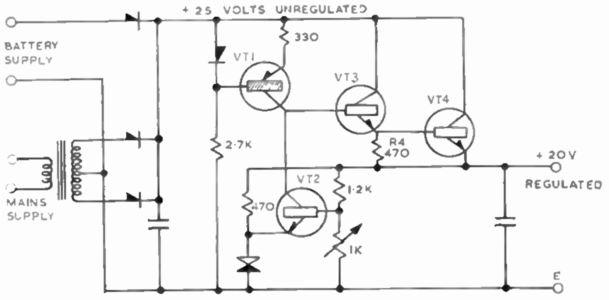

Fig. 4. Power supply (+20 V). Original circuit.

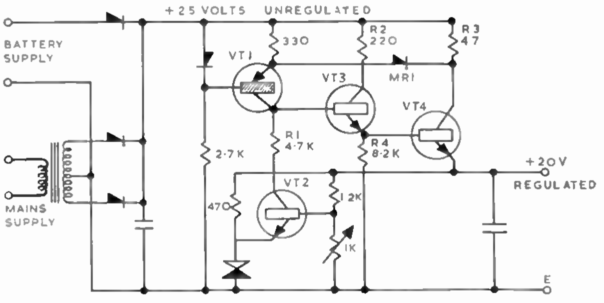

Fig. 5. Power supply (+20 V) with limiting diode.

acceptable design for a positive line series regulator circuit.

This circuit is unusual only in using *npn* transistors to give a regulated positive supply compatible with the system of stand-by batteries described earlier. In this system it is essential that the positive line series regulator is on the positive side so that the battery may be common to many instruments. The control transistor VT2 is used to compare a fraction of the regulated voltage with a 7 V reference diode. The load of VT2 is a high impedance constant current source, VT1, thus eliminating ripple and mains fluctuations from the regulated line. Output control is through the conventional drive stage VT3 and series transistor VT4.

It can be seen in Fig. 2 that if the drive transistor VT3 were to develop a short circuit due to overload, the regulating action would tend to turn VT2 hard on and thus burn it out. When this transistor had also gone short circuit there would be a low impedance path from the unregulated supply to the voltage reference diode which would be burnt out. This type of chain reaction fault is prevented by the judicious use of isolating resistors (R1, R2, R3) as shown in Fig. 5. At the same time the use of a diode (MR1) connected between the constant current source (VT1 emitter) and the collector of the series transistor (VT4), effectively protects the whole supply from short circuit on the regulated line.

4. Techniques Used in New Instruments

Space does not permit giving a complete list of new techniques made possible by using transistors but the following examples show how a radical improvement can be made over the performance that had become accepted in existing designs.

The traditional reactor period meter is an instrument requiring great care in design and installation. This is because a compromise has to be reached between the conflicting requirements of response time, noise and period overshoot. The channel uses an ionization chamber, the output current from which is proportional to the neutron flux. This current is measured in an amplifier with a characteristic giving an output reading proportional to the logarithm of the input current which is then passed to a differentiating amplifier. The output of this second amplifier is a measure of the period of the neutron flux and is generally calibrated in "doubling times".

It has become accepted that best results are obtained using the grid-cathode diode of an electrometer pentode as the logarithmic element. As the anode and screen grid circuits do not load the control grid, the input integrating time-constant is given by $C/10i$ where i is the ion chamber current (in μμA) and C is the input cable capacitance (in pF). The change of input impedance with current is useful in giving the longer time-constant found necessary at low input currents to avoid too much noise on the period amplifier output. Unfortunately it can lead to excessive period overshoot at the beginning of an exponential rise from a very low starting current. The subject has been covered theoretically and practically by Barrow and Hogg, among others.[1, 2]

In a new circuit the three conflicting requirements of response time, noise and period overshoot are satisfactorily reconciled and the opportunity is taken of achieving a very wide range of operation. To begin with, the reduction of the input time constant eliminates the period overshoot but at the expense of what would be intolerable noise in the differentiating amplifier unless the "integrating" time-constant of this second amplifier is made long. To maintain a fast response at high input currents, the noise is reduced in the second amplifier with another variable time-constant which is made a function of the input current.

A thermionic diode makes the best logarithmic element known today, but it has been little used because of the greater stability needed on its heater than in the case of the logarithmic pentode. Such stabilization is easily applied in a transistor circuit. Reduction of input time-constant could be ensured by limiting the input cable length to a few feet but is done without this limitation by placing the logarithmic diode in the feedback path of an amplifier. The factor by which the input time constant is reduced is in this case equal to the open loop gain of the amplifier and may be over 100. This is not new but the original part of the circuit is the way in which diode characteristics liable to change are compensated for by the use of a similar diode through which a constant current is maintained.[7]

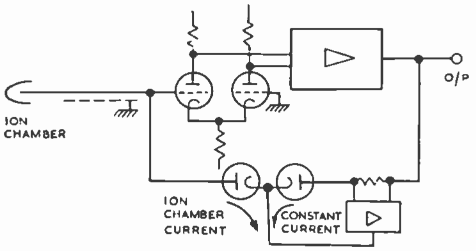

Fig. 6. Balanced logarithmic amplifier.

The operation of this circuit (Fig. 6) without diode compensation is straightforward. The electrometer input triode is balanced with a similar triode in a long-tailed pair connection and together with the transistor circuit act as a virtual earth amplifier with the logarithmic diode in its feedback loop. To all intents and purposes, the ion chamber current flows through the feedback loop, and the amplifier output is the voltage required across the logarithmic diode to ensure this. Variations in heater current (which are already small) and several other drifts are compensated by the use of a similar diode but difficulty can be experienced in the practical realization of this without degradation of performance in one way or another. If the second diode is applied to the second grid of the electrometer double triode, noise is introduced when longer input cables are used. If put in series with the logarithmic diode, the compensating diode may have to be run at a current at least ten times the top current from the ion chamber and this, if it is to have an effective compensating action will result in the loss of a decade from the instrument range.[3, 4]

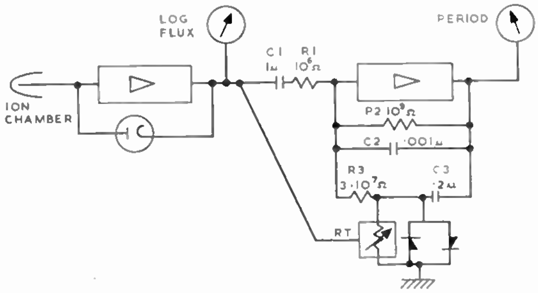

Fig. 7. Reactor period meter.

In the present arrangement a constant current is maintained in the compensating diode by a separate stabilizing circuit. This current may be less than the current taken by the logarithmic diode so that this may be used up to the limit of its logarithmic range.

On the differentiating amplifier, a long integrating time-constant is maintained at low reactor power levels but the response is progressively speeded up at higher power levels by shunting the effect of the integrating capacitor by what is effectively a power controlled resistor.[8]

In Fig. 7, the normal break points in the differentiating amplifier frequency response are given by $C_1 . R_1$ (differentiating time-constant). The capacitor C3 can be considered as multiplied by the ratio R_T/R_3 and then added to C2, thus as R_T is decreased with increasing output from the logarithmic amplifier, the integrating time constant gets shorter. The resistor R_T is here an indirectly heated thermistor and the drive circuit (not shown) can be designed to have any desired performance in controlling the value of R_T as a function of the output of the logarithmic amplifier.

No discharge of the integrating capacitor, C3, is made to the input of the differentiating amplifier when the value of R_T changes. Thus a change in "integrating" time-constant is achieved without overshoot of period indication in satisfaction of the requirement of long time-constant at low power levels but short time-constant at high power levels.

The two diodes in parallel with R_T have the effect of speeding up the response (even at low power levels) to extremely short periods. When a voltage builds up across R_T due to a high rate of change of period, one or other of the diodes will conduct thus removing the effect of C3 on the integrating time-constant.

The foregoing outline description of a reactor period meter has hardly mentioned the use of transistor techniques but it is easy to see that the design of a thermionic valve equipment to fulfil the requirements of such an instrument would lead to such complications as to make it unworkable. For example, the constant current stabilizer for the compensating diode in Fig. 6 would be complicated in valve circuitry but requires only three transistors and very little space. In fact, the whole logarithmic amplifier is contained in a sealed box little bigger than the conventional logarithmic amplifier head unit. In the same way the requirements for the differentiating amplifier are more exacting and a further amplifier required to drive the heater of the thermistor. A complete description of the reactor period meter will appear shortly.[5]

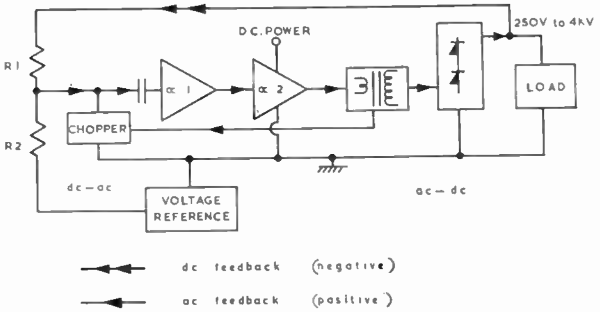

Fig. 8. Highly stable transistor e.h.t. converter.

The polarizing supply for the ionization chamber of a period meter channel is normally obtained from a battery of dry Leclanché cells. This battery is liable to become noisy with consequent ill effects on the period meter so that frequent battery replacement is called for. A highly stable h.t. supply has been developed[9] using a chopper transistor at the comparator point and a resistor chain to compare the output of 600 V with a 5-V reference (Fig. 8). Positive feedback is used to drive the chopper transistors and this regeneration obviates the need for a phase sensitive output rectifier which would be almost impossible at 600 V.[6]

In line with the requirement for all reactor control instruments to be operable directly from a d.c. stand-by supply, a small potentiometric recorder has been developed. This recorder is being made in a single trace and six point version. With a calibrated chart width of 4 in. and using a panel cut-out of only 6 in. square it will enable a major change in instrumentation policy to take place in easing the layout arrangement on a control desk and making possible economy of panel space. All the usual facilities of larger recorders are available including sensitivity of 0·2% (0·5% accuracy including allowance for paper stretch), a full scale span of 1 mV to 200 mV and paper speeds up to 12 in/min.

5. Conclusion

The future trends appear to be toward instruments with a wider range; the period meter described will measure reliably an ionization chamber current ten times that usable on presently available commercial equipment; the request from users is for higher count rate maxima on pulse counting channels. Transistors are now well able to cope with this requirement if enough design effort is put in to overcome their peculiar shortcomings. The low power consumption and good switching properties of these and related devices are most attractive when considering the complete replacement of relays in reactor safety circuits. Trip circuits with a.c. or pulse operation can be made to trip and reset continuously and this goes a long way to making them self-monitoring. In fact an entire channel including ionization chamber can be designed using a.c. signals throughout.

To date only individual instruments or channels have been considered but a reactor is being re-instrumented with transistor equipments by the U.K.A.E.A. At the same time a solid-state safety circuit is being installed and the operation of this reactor should provide valuable practical information on the implementation of present ideas and will be able to confirm the improvement of reliability to be expected from the general use of solid state devices.

6. References

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5. E. P. Fowler, "A new reactor period meter". A.E.E.W., R 170. (To be published.)
6. E. P. Fowler, "Transistor H.T. Converter", A.E.R.E. report M.693, May 1960.
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9. U.K. Atomic Energy Authority, British Patent Application No. 19,304/60.

Manuscript first received by the Institution on 2nd December 1961 and in revised form on 23rd February 1962. (Paper No. 735.)

Symposium on Sonar Systems at The University of Birmingham

Sponsored by The British Institution of Radio Engineers (Electro-Acoustics and Radar Groups), The Institute of Physics and Physical Society (Acoustics Group), and the Electrical Engineering Department of The University of Birmingham.

Monday, 9th July

Morning. PROPAGATION I

Absorption of Sound in Sea-Water. M. SCHULKIN and H. W. MARSH (Avco Corporation).

Motion-Induced Sea-Bed Echo Amplitude Fluctuations. B. K. GAZEY (University of Birmingham).

The Effect of Ice on Long Range Underwater Sound Propagation. J. D. MACPHERSON (Naval Research Establishment, Canada).

Afternoon. SURVEY EQUIPMENT

Profile and Area Echographs for Hydrographic Survey of Waterways. S. FAHRENTHOLZ (Kiel, Germany).

Reflection Seismic Methods for Exploring the Sediments and Crust of the Earth beneath the Oceans. J. B. HERSEY, E. E. HAYS, D. D. CAULFIELD, H. E. EDGERTON and S. T. KNOTT (Woods Hole Oceanographic Institution).

Short Contributions

A High-resolution Electronic Sector-scanning Sonar. V. G. WELSBY and J. R. DUNN (University of Birmingham).

A New Sonar System for Marine Research Purposes. T. S. GERDHARDSEN (Simonsen & Mustad A/S, Norway).

Measurements of the Target Strength of Fish. F. R. HARDEN JONES, R. MITSON, D. H. CUSHING (Fisheries Laboratory, Lowestoft) and G. H. ELLIS and G. PEARCE (Kelvin Hughes).

The Thumper System used by N.I.O. R. BOWERS (National Institute of Oceanography).

Tuesday, 10th July

Morning.

Prediction Methods for Sonar Systems. R. J. URICK (Naval Ordnance Laboratory, U.S.A.).

SONAR FOR FISHERIES

The Fisheries Application of Sonar. R. E. CRAIG (Fisheries Laboratories, Aberdeen).

Cathode-Ray-Tube Displays for Fish Detection on Trawlers. P. R. HOPKIN (Kelvin Hughes).

A High-speed Triggered Echo-Sounder Recorder having Sea-bed Lock. R. W. G. HASLETT (Kelvin Hughes).

Afternoon. PROPAGATION II

Some Researches on Propagation Using the Techniques of Ray Path Acoustics. R. E. ZINDLER (Pennsylvania State University).

The Uses of Ray Tracing in the Study of Underwater Acoustic Propagation. M. J. DAINTITH (Admiralty Underwater Weapons Establishment).

Propagation of Sound in Shallow Water. D. E. WESTON (Admiralty Research Laboratory).

Directional Distribution of Ambient Sea Noise. B. A. BECKEN (U.S. Navy), P. RUDNICK and V. C. ANDERSON (Scripps Institution of Oceanography).

Wednesday, 11th July

Morning. ARRAYS AND SIGNAL PROCESSING

Space-Time Sampling and Likelihood-Ratio Processing. P. L. STOCKLIN (Office of Naval Research, U.S.A.).

Directional Characteristics of Volume Arrays. J. W. HORTON (Navy Underwater Sound Laboratory, U.S.A.).

Visual Display of Integrated Video Waveforms. D. C. COOPER (University of Birmingham).

Afternoon. Short Contributions

The Angular Resolution of a Receiving Aperture. V. G. WELSBY (University of Birmingham).

Multiplicative Reception in Radio-Astronomy and Sonar Systems. D. G. TUCKER (University of Birmingham).

The Effect of Area of Target Paint on Visual Detection. J. W. R. GRIFFITHS and N. S. NAGARAJA (University of Birmingham).

Optimum Processing for Acoustic Arrays. W. VANDERKULK (Scripps Institution of Oceanography).

Investigation of an Interaction Anomaly between Sound Projectors Mounted in an Array. J. S. M. RUSBY (Admiralty Research Laboratory).

On the Improvement of Detection and Precision Capabilities of Sonar Systems. M. FEDERICI (University of Milan).

Synthesis of Multi-element Directional Patterns with a Two-element Single Frequency Receiving Array. E. D. R. SHEARMAN (University of Birmingham).

The Detection of Sonar Echoes in Reverberation and Noise. J. O. ACKROYD (Admiralty Underwater Weapons Establishment).

Thursday, 12th July

Morning. Visit to the Underwater Laboratory of the University of Birmingham.

Registration forms may be obtained from the Institution at 9 Bedford Square, London, W.C.1.

Radio Engineering Overseas . . .

The following abstracts are taken from Commonwealth, European and Asian journals received by the Institution's Library. Abstracts of papers published in American journals are not included because they are available in many other publications. Members who wish to consult any of the papers quoted should apply to the Librarian, giving full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. Translations cannot be supplied. Information on translating services will be found in the Institution publication "Library Services and Technical Information".

VISUAL THRESHOLDS IN TELEVISION

A quantitative theory for calculating thresholds in black-and-white vision is given in a recent Australian paper. For this purpose a linear model was postulated, the input to which are normal visual patterns and the output an energy level distribution in terms of which visual thresholds can be taken as a fixed constant. The model is shown to be in agreement with the laws on visual thresholds and with published results. The theory is used to calculate the relative visibility of noise components in the video frequency spectrum and it is shown that at the high frequency end noise should suffer a subjective attenuation approaching 12 dB/octave. This agrees well with published measurements. The difference in factors determining the visibility of wanted signal and noise is also discussed quantitatively.

"Visual thresholds and the visibility of random noise in television", Z. L. Budrikis. *Proceedings of the Institution of Radio Engineers Australia*, **22**, pp. 751–9, December 1961.

COMMON CHANNEL BROADCASTING WITH FREQUENCY MODULATION

When two signals are frequency modulated with the same information and arrive simultaneously at a receiver, characteristic interference effects are produced which impose certain limits on the application of common channel broadcasting networks. The theory of these interference effects has been discussed by a German engineer and their elimination in operation of common broadcasting networks is described.

"Common broadcasting with frequency modulation", A. Essmann. *Nachrichtentechnische Zeitschrift*, **14**, pp. 609–15, December 1961.

OVERLOAD PROTECTION FOR TRANSISTOR EQUIPMENT

Transistor amplifiers and other transistorized equipment feeding long transmission lines or inserted into such lines and fed from mains power supplies are subjected to interfering voltages and currents as well as load changes. After pointing out the sources of this interference, a recent German paper explains briefly some well-known protective measures. A detailed description is given of three particularly effective circuits, namely for voltage, current and power protection.

"Overload protection devices for transistor equipment, especially transistor amplifiers", L. Gohm. *Nachrichtentechnische Zeitschrift*, **14**, pp. 605–8, December 1961.

AUTOMATIC TRACKING OF RADAR DATA

The rapid advances made in the design of complex digital systems have, for some time now, made it possible to contemplate automatic detection and tracking of aircraft by means of search radars. A French paper has discussed the mathematical aspects of the problem of the reconstitution of aircraft tracks in the horizontal plane. It is shown that this problem is identical to that of filtering digital or sampled information. The sampling period is equal to the rotation of the search radar antennas used with the automatic tracking system. By using the mathematical operator, which is the Z transformation, as well as the evaluation criteria normally used in any sampling system, an analysis is given of absolute stability, relative stability and fluctuation filtering efficiency of the tracking system, under examination. These results are given in terms of two parameters α and β which are characteristic of the tracking loop. The method used for obtaining the response of the sytem to a realistic trajectory, with or without detection gaps, is given. The usefulness of the Z transformation is again demonstrated in the examination of the stability of an automatic initiation of the tracks. This process is examined from the probability point of view and is related to a Markow process. The presence of false echoes at the detector may cause a divergence in the automatic initiation, i.e. it may generate a continuously increasing number of tracks. The operator Z^{-1} of the Z transformation is then used as the delay operator to permit easy examination of the increase in the number of tracks with time.

"Use of the Z transformation in the study of automatic tracking of radar data", J. P. Gouyet. *Annales de Radioélectricité*, 67, pp. 30–58, January 1962.

WOOMERA COMMUNICATIONS NETWORK

The communications network which has been established at Woomera for the transmission and dissemination of speech and data required for the conduct of missile trials, is described in a recent Australian paper. The make-up of this network, which is constantly being modified and extended to cope with the changing roles demanded of it, exemplifies how one phase of engineering design and development being carried out at the Weapons Research Establishment is closely associated with the conduct of scientific experiments and the missile trials programme at Woomera.

"The Woomera communications network", E. B. Davis. *Institution of Engineers, Australia, Electrical and Mechanical Engineering Transactions* EM3, No. 2, pp. 53–68, November 1961.

TROPOSPHERIC SCATTER

A survey has been given by a Dutch engineer of the use of tropospheric scatter for transmission at ultra-high and super-high frequencies (decimetric and centimetric waves) beyond the horizon. Such links are characterized by a number of specific properties, e.g. an additional attenuation in the scatter volume, accompanied with rapid and slow fading and a limited bandwidth for the information to be transmitted. The disadvantages caused by rapid fading can be met by applying diversity reception, the influence of slow fading can only be compensated by a sufficient reserve of transmitting power. Details are given of the principal tropospheric scatter links in operation at present. The Netherlands PTT has carried out propagation measurements on a 180 km overwater path to investigate whether a scatter link to England over the North Sea is possible. A short description is given of the equipment used for this purpose and of the most important results.

"Telecommunication by means of tropospheric scatter", A. de Jong. *Het PTT-Bedrijf*, **2**, No. 2, pp. 71–95, January 1962.

TRANSISTOR APPLICATION

In general it is found that noise and distortion requirements for a radio frequency amplifier are not compatible. In a recent Dutch paper it is shown that noise and distortion have minimum values if the transistor is driven from a high-impedance source. However, both increase to a certain extent when there are selective couplings between the stages of the amplifier although a high-impedance source for the transistor is still worth while. An a.g.c. circuit making use of the exponential character of a semi-conductor is described and it is claimed that this circuit minimizes distortion.

"The application of transistors in the h.f. amplifier of a communication receiver", G. Rosier, R. I. G. Bosselaers and J. Noordanus. *Tijdschrift van het Nederlands Radiogenootschap*, **26**, No. 4, pp. 135–57, 1961.

PARAMETRIC AMPLIFIER OPERATION

In a recent Japanese paper an analysis is presented which expresses the pump frequency component of the barrier capacitance of the back-biased step-junction diode in a closed form of complete elliptic integrals whose value when excited by a large swing sinusoidal pump voltage can be easily derived from function tables. It is shown that the d.c. component, which is considered to be independent of the pump voltage when the swing of pumping is small, must be treated as a function of the pump voltage and expressed in the same form as above. A theoretical investigation of the gain stability of the parametric amplifier under large swing pumped conditions is presented which provides theoretical expressions of the gain fluctuation sensitivity caused by pump voltage fluctuations. In conclusion several relations between gain stability and circuit parameters are explained and experimental results obtained are given to verify the theory.

"Gain fluctuations of the parametric amplifier under large swing pumped conditions", Tadashi Fuse. *The Journal of the Institute of Electrical Communication Engineers of Japan*, **44**, No. 10, pp. 1488–95, October 1961. (Synopsis in English.)

BANDWIDTH ECONOMY FOR TELEVISION

A Czech engineer describes in a recent paper investigations into the permissible narrowing of the frequency band for the transmission of colour information in the form of R–Y, B–Y difference signals related to a nominal value of 1·6 Mc/s per 6dB, as anticipated for the transmission of colour television pictures according to a O.I.R.T. television standard. By using the colour transition criterion the permissible narrowing is determined experimentally; the values found in this way are 1·32 Mc/s per 6dB in the R–Y colorimetric axis and 1·17 Mc/s per 6dB in the B–Y colorimetric axis. The threshold decrease of colour sharpness is determined experimentally by means of the static colour picture criterion; it is found to be 0·93 Mc/s per 6dB in either colorimetric axis.

"Experimental determination of the permissible narrowing of the frequency band for the transmission of colour information according to the O.I.R.T. television standard", J. Cajka and B. Pospisil. *Slaboproudy Obzor*, **6**, pp. 720–4, December 1961.

SCREENED ROOM DESIGN

A screened room (4 × 2 × 2·30 m) suitable for microwave experiments is described in a recent Dutch paper. Floor, walls and ceiling are constructed from 1-mm copper sheets. Ventilation is provided by clusters of air channels, 7 cm long and 1 cm^2 in cross-section, which act as waveguides with a limiting frequency of 15 000 Mc/s and thus do not impair the screening. The interior of the room can be observed from outside through a similarly designed window with the aid of a convex mirror. The penetration of interference through the supply cables is prevented by means of a network filter combined with two simple coaxial filters. Radiation from a transmitter outside the closed door is attenuated by at least 150 dB at wavelengths of 300 m and 3 m, by 45 dB at 7·5 cm, and by 25 dB at 3 cm. With the transmitter opposite a ventilation grid or the filter unit the attenuation is $>$ 150 dB at all the wavelengths mentioned.

"An electrically screened room for microwave experiments", A. J. F. de Beer. *Philips Technical Review*, **23**, No. 5, pp. 155–8, 1961–2. (In English.)

MAGNETIC DRUM STORAGE FOR TELEVISION

A new storage device, consisting of a magnetic drum with 44 slots on to which magnetic tape is wound has been designed in Japan for television recording. In order to avoid the difficulties involved in recording television signals having a wide frequency band, the system employs frequency modulation. Frequency modulated signals are electronically sampled to pick up four fields per second. One field signal is recorded on one track of the drum, and two heads which alternatively touch the magnetic drum are provided to pick up the reproducing signals continuously. The slots in the drum give close contact between the heads and the tape for high storage density, and also reduce the effect of eccentricity.

"A new magnetic drum type memory device for television signals", E. Kimura and K. Yokoyama. *The Journal of the Institute of Electrical Communication Engineers of Japan*, **44**, No. 6, pp. 984–55, June 1961. (Synopsis in English.)

COMPOUND PNPN SWITCHES

In the usual bistable electronic switches, the current direction in the conducting state is generally limited in only one direction. Therefore, the field of application of electronic switches will be extended by the realization of bidirectional-bistable electronic switches.

In a recent Japanese paper, the fundamental characteristics of the compound *pnpnpn* diode and its variations made by combination of one *npn* transistor and two *pnp* transistors are examined from the point of view of developing the bidirectional-bistable electronic switch. The results of this study show that the compound *pnpnp* diode (or compound *npnpn* diode) can be used as a bidirectional-bistable switch. The multi-terminal compound *pnpnp* devices exhibit some interesting characteristics which are usable in controlling these devices. The development of single-element bidirectional-bistable switches is also suggested.

"Compound *pnpnp* switches for bidirectional-bistable electronic switches", K. Yamagishi. *Review of the Electrical Communication Laboratory, NTT*, **9**, No. 9–10, pp. 545–51, September–October 1961. (In English.)

RADIO METEOROLOGY

The basic principles of radio meteorology are summarized in a recent German paper and its significance in the propagation of metric, decimetric and centimetric waves is discussed. Particular importance is given to the problem as to whether the refractive index in the vicinity of the ground may be replaced by the refractive modulus near the ground. Methods are derived from these results to forecast the daily and annual variations in the propagation loss.

"Radio meteorology and its significance in long distance propagation of metric, decimetric and centimetric waves", B. R. Bean, L. Fehlaber and J. Grosskopf. *Nachrichtentechnische Zeitschrift*, **15**, pp. 9–16, January 1962.

GUIDED WAVES OF RECTANGULAR SYMMETRY

Reiterative wave beams are wave beams whose cross-sectional field distribution is repeated at periodic intervals by passing the wave beams through a structure of equally spaced phase-correcting devices that re-establish the cross-sectional phase distribution. If the beams are composed of elementary plane waves whose directions of propagation form only a small solid angle around the beam axis, a system of wave beams can be derived which is reiterated by the same phase-correcting structure. These wave beams are called "beam modes", since they satisfy orthogonality relations similar to the modes in a waveguide and in the paper are assumed to be rectangular symmetry. As infinitely extended phase correcting devices are assumed, the field distribution of the beam modes is determined by Hermite polynomials in the case of rectangular symmetry and by Laguerre polynomials in the case of cylindrical symmetry. It is claimed that if the phase correcting devices limit the beam cross-section, the mode functions are modified and, in addition, there is an iteration loss.

"Reiterative wave beams of rectangular symmetry", F. Schwering. *Archiv der Elektrischen Ubertragung*, **15**, pp. 555–64, December 1961. (In English.)

POST-DEFLECTION CATHODE-RAY TUBES

In order to increase the deflection sensitivity of cathode-ray tubes, post-deflection is frequently adopted and in a recent German paper it is shown that efficient post-deflection can be obtained with relatively little expense. It is demonstrated however that any kind of post-deflection system causes an enlargement of the beam spot on the screen which is always greater than the increase in sensitivity. Therefore it is concluded that the principle of post-deflection cannot be used effectively to increase the sensitivity of cathode-ray tubes.

"Cathode-ray tubes with post-deflection", W. Thommen. *Archiv der Elektrischen Ubertragung*, **15**, pp. 565–8, December 1961.

VERTICAL MOTIONS OF THE F-LAYER

It is explained in a paper by a German engineer how electron density of the F-layer, as derived from Lindau ionograms of the years 1957–60, showed during a very strong geomagnetic bai disturbance a total vertical shift of 200 km with a vertical speed of about 30 m/s. For geomagnetically very calm nights short-time height variations of two to three hours duration could be found at times with a vertical shift of 60 km. The height interval within which the maximum of the F-layer can be encountered in different nights of the winter months is about 120 km. In the summer this range amounts to about 30 km only. The rise of the F-layer in the evening and its lowering after midnight show no relationship with the optical sunrise and sunset at the level of the F-layer. The rise takes place between 2000 and 2100 G.m.t. For the winter months a rise of about 40 km was found. It is further shown that spread-F-echoes of even strong intensities can be observed during geomagnetically very calm nights at Lindau/Harz and that these by no means have to be a consequence of greater vertical motions of the F-layer.

"Vertical motions of the F-layer", W. Becker. *Archiv der Elektrischen Ubertragung*, **15**, pp. 569–77, December 1961.

COLOUR TELEVISION TUBES

In direct-viewing tubes for colour television, use has hitherto been made of a phosphate for the red-fluorescent phosphor and of a silicate for the green-fluorescent phosphor. The sulphide (ZnCd)S-Ag, which fluoresces red or green depending on the CdS content, has substantially better properties (lower persistence, higher efficiency). Applied by the conventional method, however, the red-fluorescent sulphide does not adhere well to the tube face.

A new method giving good adhesion is described in a recent Dutch paper in which a suspension containing the red-fluorescent sulphide is hardened by ultraviolet irradiation through the glass instead of from the gun side. The other phosphor patterns are coated with a dye to prevent the red-fluorescent phosphor from sticking to them. The result is a screen on which moving images are much sharper and which has 40 to 50% higher luminance.

"An experimental fluorescent screen in direct-viewing tubes for colour television", R. R. Bathelt and G. A. W. Vermeulen. *Philips Technical Review*, **23**, No. 5, pp. 133–41, 1961–2. (In English.)

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