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——TECHNICAL AND COMMERCIAL TOPICS OF CURRENT INTEREST TO THE ELECTRONICS INDUSTRY

CONTENTS

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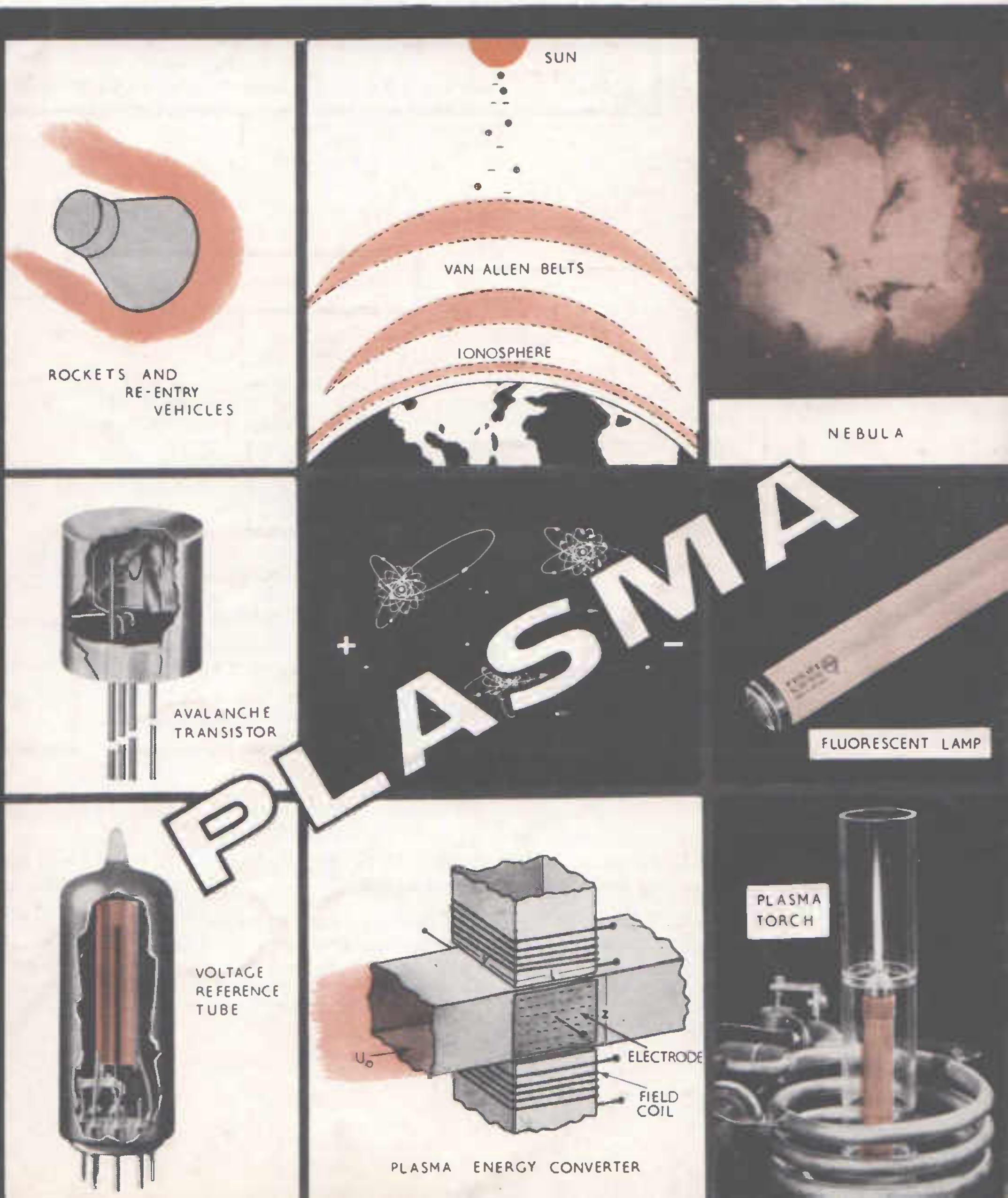


Plasma

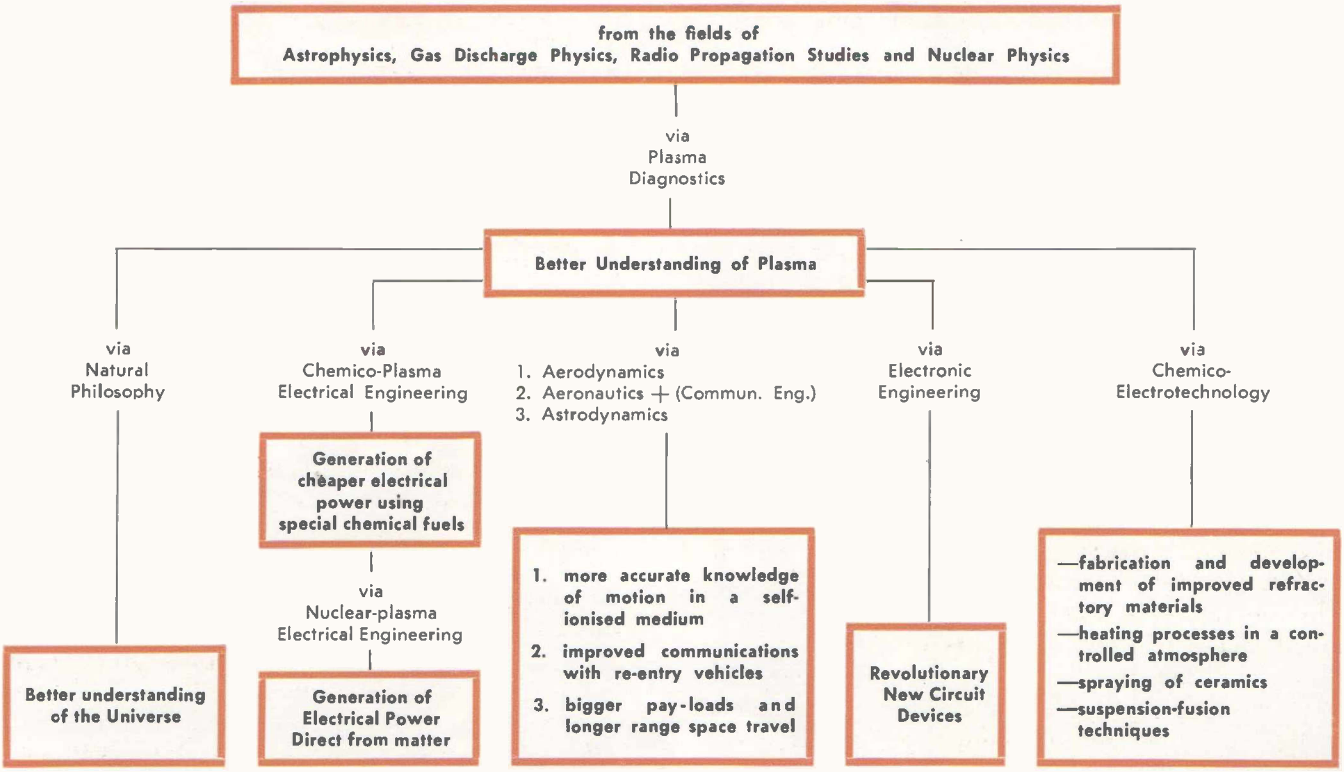
Part 1 —its impact on human endeavour

Plasma—which in the form of ionised gases pervades vast regions of the Universe, and which has been used for almost a century in gaseous electron tubes—has, in the last few years, taken on a new significance. The recent synthesis of concepts, techniques and stored-up knowledge derived from several fields, has led to a rather sudden realisation—by engineers especially—of its enormous potentialities.

In Part 1 the role played by Australian workers in the field of Plasma physics — and engineering — is traced, and some important contributions by scientists within the Philips Organisation are presented.

Part 2, to appear in the next issue of the "Digest", is devoted to immediate practical applications of Plasma: in particular, it will describe several Plasma (or "Electronic") Torches, developed within Concern laboratories.

The Plasma Development Chain



Plasma—Defined

As originally used by Langmuir and Tonks in 1929 the term "plasma" denoted a gas in which an important fraction of the molecules was dissociated into ions and electrons, the gas as a whole remaining electrically neutral.

However, at present, the concept is extended to any mixture of particles (obeying certain constraints)(1) *some of which are charged, and where the percentage of the mixture that is ionised contains approximately equal numbers of positive and negative particles, so that the overall aggregate can be considered electrically neutral. The latter definition is not limited to the gaseous state, and includes possible microplasma formation in crystals of semiconducting material. However, a gaseous state is generally implied, the degree of ionisation being such that the "gas" becomes conductive enough to be affected by magnetic fields.*

PLASMA

The behaviour of plasma can be visualized as that of an electrically conducting fluid. The interaction of such "plasma streams" with magnetic fields has long been studied under the name "magneto-hydrodynamics" (MHD) by astrophysicists concerned with the origin of stars. It is precisely this interaction which is currently being considered for possible large scale power generation using MHD converters(2). However, more logically, electrical power generation by such means often now makes use of the term "magneto-plasma dynamics" (MPD).

PLASMA—In Nature

(a) Solar and Astro-Physics

It is now considered that the energy of the sun is derived from internal thermonuclear reactions in which energy is released by the nuclear fusion of protons to form neutral helium atoms. This process which proceeds slowly, establishes temperatures at the sun's interior which are in excess of 20 million degrees. Now at temperatures above 20,000°K most gases become 100% ionised, and so the inner region of the sun may be considered as a gigantic pure plasma. Actually, the bulk of matter in the Universe, that in the stars, exists essentially in the ionised state. However, due to the large masses (and consequently large gravitational forces) involved, we are then dealing with *confined* plasma.

The new art of radio astronomy is, of its very nature, linked with plasma phenomena. The chance observation of extraterrestrial radio waves in 1931 led to the development of more powerful tools for probing the Universe, a field in which both Australia and Holland have played important roles: (see for example references (3) and (4)). A radio telescope has advantages in that it presents a wider "space window" of some 10 decades bandwidth, and that optical scattering by interstellar dust is avoided.

The spectrum observed is basically a continuum, with only one discrete spectral component being observed. This discrete emanation is the 21 cm (1420 Mc/s) spectral line originating from rare transitions in interstellar hydrogen atoms; its detection was predicted in 1944 by van de Hulst. Amongst sources of continuous spectral radiation are hot ionised hydrogen gas surrounding the hot stars, and those attributed to non-thermal effects such as "synchrotron" radiation and the so called "free-free" transitions. The former term implies radiation associated with electrons whose velocities approach the speed of light and which move in helical orbits about lines of magnetic force: the latter implies radiation associated with electrons accelerating on approaching protons, and it originates from ionised hydrogen gas in the plane of our Galactic system.

(b) The Ionosphere

As the ionising radiation from the sun (principally ultraviolet and X-ray radiation) penetrates deeper into the earth's atmosphere it encounters an ever increasing density of gas particles. Thus for radiation of a particular intensity, there will exist a height, dependent on the gas density gradient and its radiation absorption properties, where the rate of electron production is greatest, and an ionised layer is thus formed. In order of increasing distance from the earth's surface we then have what are termed the D, E and F layers of the *Ionosphere*. Ultraviolet rays from the sun's chromosphere and corona are almost wholly responsible for layers D and F. However, during solar "flares" medium length X-rays, emitted by the corona, strongly enhance the ionisation of these layers and lower their altitude, blacking out radio communications. Layer E is formed by the longer X-rays emitted by the corona.

(c) Van Allen Radiation Belts, Geomagnetic Storms and Auroras

In addition to the "trapping" action of the earth's atmosphere, as described in (b) above, the earth's magnetic field is instrumental in trapping particles from the sun and outer space. This was perhaps the most surprising discovery of the recent International Geophysical Year. Two radiation belts are formed, these being termed the Van Allen belts. Each is a torus-shaped belt (one within the other) surrounding the *globe* in such a fashion as to enclose all but the magnetic polar regions.

The outer belt is thought to be due to, and maintained by, streams of neutral plasma consisting mainly of protons and electrons which are ejected from time to time from the sun. These streams are considered to be ejected at extremely high velocities and hence confined by the strong associated magnetic fields (a natural example of the "pinch" effect which is treated later). On encountering the earth's magnetic field, the particles assume complicated trajectories within the confines of the outer belt. This belt changes considerably in extent and intensity depending on solar activity.

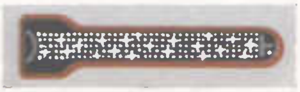
The inner belt is ascribed to strong cosmic rays from space which are even more energetic than solar particles. On entering the rarified upper atmosphere, neutrons are formed by collision which later disintegrate, forming protons and electrons. These latter, trapped by the earth's inner magnetic field, again perform complex trajectories, but this time within the confines of the inner belt.

At times, the solar chromosphere becomes turbulent and vortices ("sunspots") appear, this activity (in number and magnitude) reaching a maximum about each 11 years. One of the results of solar eruptions is an enhanced plasma discharge which results in geomagnetic "storms". During these periods, the streams of plasma can then find their way into the regions of the magnetic poles (auroral zones) where electrical

Plasma in Gas-filled Tubes

Thyratron and grid-controlled rectifier

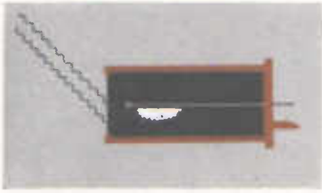
Industrial rectifying tube



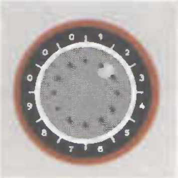
Gas noise source

Voltage stabilising and reference tubes

Rare gas cartridge

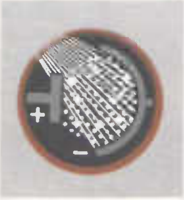


Radiation counter tube



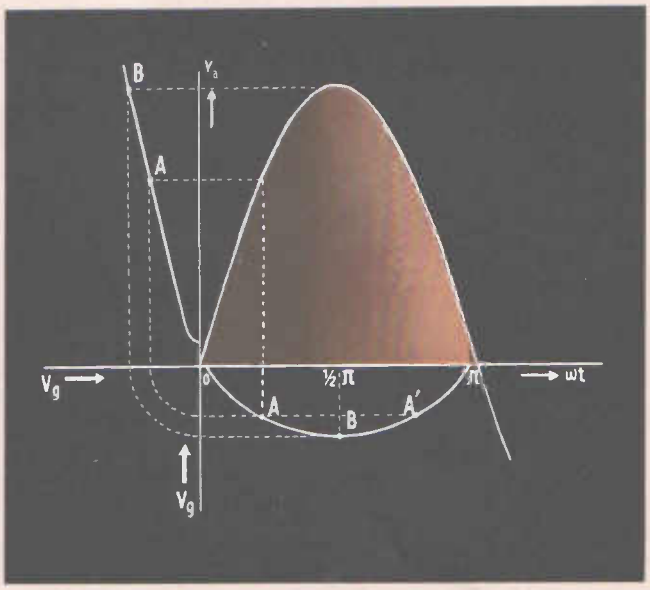
Decade counter tube

Trigger tube



Gas-filled phototube

Ignitron



Thyratron envisaged as a "plasma switch"

currents of millions of amperes are formed, seriously distorting the normal magnetic fields around the polar regions.

It was during the course of IGY that it came to be known that auroras could be created by abnormalities associated with the outer Van Allen belt. Ordinarily this belt remains above the denser atmospheric regions; however during sunspot activity the belt drops lower and ionisation of the earth's atmosphere can result. This will occur near the polar regions where the outer belt is in closest proximity to the earth. On collision with nitrogen and oxygen of the atmosphere, the particles of the belt give rise to X-rays and spectacular light emissions. These emissions are known as "auroras", the colouration depending on the altitude at which collision occurs.

Amongst other natural manifestations of plasma, one should not forget to mention lightning,(5) which has been known to man since his beginning.

PLASMA—Artificial

(a) Low Temperature Plasmas

Amongst these we may list a number of devices which have been familiar entities for years past.

Firstly, there are those electron tubes in which the envelope has been filled (after evacuation) with an inert gas, e.g. argon or helium, or which operate with mercury vapour. These can be classified as to whether the emission is obtained from a thermionic cathode, cold cathode, photocathode or pool cathode.

In the first class we have transmitting and industrial rectifiers, battery charger tubes, thyratrons, plasmatrons and gaseous noise diodes. In the second class appear voltage stabilising and reference tubes, surge arrestor, radiation counter and gas-filled numerical indicator tubes together with the controlled devices known as trigger tubes.

Representative of the third class is the gas-filled photocell, whilst exitrons and ignitrons fall into the last category.

It is also worth mentioning that the omegatron (described in the May issue of the *Digest*) depends for its action on the ionisation of a residual gas sample by means of an electron stream. The plasma so formed, is then subjected to both a static magnetic field and an applied HF electrical field. Although intended for low pressure gas studies (10^{-5} mm Hg max.) it is to be realised that the Penning discharge (to be described hereunder) which has had important application, also takes place at pressures as low as 10^{-12} mm Hg. It would thus appear that omegatron technique has not as yet reached its full potential.

In addition to the above devices we have the discharge lamps used for highway, industrial and domestic lighting. These comprise fluorescent, sodium and mercury vapour lamps and neon tubes.

Representative items from those listed above are illustrated opposite. In particular the thyratron has been visualised therein as a "plasma switch".

Low temperature plasma phenomena have been described by Penning(5)

The plasmas formed in the above devices however, usually have a low charge density with the fractional ionisation ordinarily less than 1%. Even though this small percentage ionisation is sufficient to provide good electrical conductivity, it is difficult to study theoretically because of numerous competing processes. On the other hand, these are *confined* plasmas, the confining processes having no attendant difficulties.

In addition to these low temperature discharge devices, other devices are possible for the generation, amplification and guidance of microwave energy. The passage of an electron beam through a magnetically confined plasma can result in either generation or amplification of microwave energy.

Plasma waveguides are being investigated, which exhibit mode and bandpass characteristics controllable by external magnetic fields. In addition, phase shifters, attenuators, microwave energy detectors and waveguide switches are either being realised or in advanced development.

Devices utilising Faraday rotation, and those using plasma non-linear effects, are similarly being developed. Microwave mixers, plasma parametric amplifiers, and harmonic generators of millimeter waves fall into this class.

A quantum plasma device functioning as a maser, has also been reported.

In addition to the above, many of the effects currently being observed in semiconductors can be attributed to effects analagous to those occurring in gaseous plasmas. Consequently, gaseous plasma knowledge can aid in the understanding and development of new semiconductor devices; (for example, the avalanche transistor exhibits "microplasma" phenomena.) Conversely, the more stable medium of solid state can be used to advantage in isolating and studying some of the competing processes occurring in gaseous plasmas; in particular, noise phenomena are much lower in the solid state. It is considered that the plasma of moving electrons and holes will receive some prominence in the future.

(b) High Temperature Plasmas

In considering high temperature plasmas of terrestrial design we are faced with a fundamental confinement problem. Gravitational forces are insufficient in such cases (unlike celestial bodies of enormous mass). Furthermore, we cannot always think in terms of an enclosing vessel since the more useful temperatures envisaged are either close to, or exceed, the fusion point of even the highest grade refractories. Hence, for those instances where close confinement is essential, a magnetic means must be utilised (e.g. "pinch", "mirror" or "cusp" confinement, etc.).

(*i*) *Electro-nuclear Engineering*

The fundamental goal of peaceful thermo-nuclear research(6) is the production of economic power from the controlled release of fusion energy. In addition to the low cost and abundance of fuel required, the fusion (in contrast to fission) reaction holds the promise of being inherently safe in that there would be no possibility of "run-away" reactions. In addition, the fusion products are non-radioactive. In particular, the possibility exists of direct generation of electrical power by the elimination of the inefficient heat cycle.

Fusion implies the combination of certain light nuclei into heavier components whose mass is less than the sum of the masses of the original constituents, this mass discrepancy being converted to energy. However, for fusion to occur, temperatures of the order of 10^8°K must attain, implying fully ionised gases (i.e. perfect plasma). Furthermore, this involves confinement at such elevated temperatures for an appreciable fraction of a second.

Of the several methods available for heating the plasma the simplest is by "Joule heating", i.e. using the plasma current itself which also provides the confining field; (interparticle collisions must occur to provide any Joule heating). Once the thermo-nuclear process commences it will be indicated by an increase in the number of neutrons.

At the present time interest has turned to the weakly ionised gases obtainable from chemical combustion. The temperatures reached are insufficient for any form of magnetic containment to be feasible, and serious material technology problems have therefore to be solved. However, the gain in overall efficiency made possible by commencing thermodynamic cycles at temperatures of the order of 3000°K (compared with the maximum turbine temperatures of less than 1000°K), obviously make such investigations very worthwhile.(2) Furthermore, electrical energy could then be readily extracted from the plasma by means of a MHD (or MPD) converter.

If a DC magnetic field is applied in a direction perpendicular to a plasma stream an electric field is generated in a direction normal to both the magnetic field and the fluid flow. If now electrodes connected to an external load are appropriately placed, this electric field will cause a current to flow in the external circuit. Energy is transferred to the load at the expense of the kinetic energy of directed motion of the conducting fluid. This is the basis of the MHD converter, which has no moving parts. MHD generators are also applicable to AC power generation. Messerle and Morrison(7) have investigated the conditions under which there is a maximum power transfer to the electrical load circuit and have obtained a maximum power transfer theorem.

However considerable research is still required before practical and economical plasma converters can be built. Experience with experimental converters using plasma torches and shock tube equipment is still much too restricted(2) to allow of definite conclusion as to the immediate future of these devices.

Returning to the idealistic thermonuclear power source—The two main schemes for confining the hot plasma are by "pinch" effect and by "magnetic-trap". In the former case the confining force is derived from the magnetic field set up by the current thus constrained to flow in the plasma itself, whereas in the latter case the magnetic fields confining the plasma are generated by circuits external to the plasma.

Plasma Symposia

The application of plasma to power generation is the topic of various current symposia throughout the world, e.g., Kings College, University of Durham, Newcastle-on-Tyne, September (6-8); it will also be thoroughly treated at the coming World Conference, 6th plenary session, to be held in Melbourne during October (20th-27th). Further, a school on Discharge and Plasma physics will be held at the University of New England (Jan. 24—Feb. 3, 1963). This has been arranged in association with the University of Queensland in order to bring together Australian physicists and engineers who are concerned with the field. The lecturers will include overseas authorities.

(ii) *Aerodynamics, Aeronautics and Plasma Propulsion Techniques*

Supersonic airborne vehicles influence their environment profoundly. Accompanying the shock wave is an increased air temperature which gives rise to ionisation and consequent conductivity. The equations of gas dynamics are modified by the conductivity of the plasma medium.

When considering the re-entry of space vehicles we must also consider the plasma generated by their passage through the atmosphere. This conducting plasma sheath creates great communications problems and, further, affects radar return. These problems are being effectively overcome.

Besides the problems created by plasma in these allied fields, there are also some advantages. The high temperatures of rocket flames are accompanied by appreciable ionisation which may be an important consideration. Recently, the desirability of extremely high velocity rocket exhaust has led to attempts to use electrically accelerated particles for rocket propulsion. Such devices include ionic accelerators and neutral plasma (or MHD propulsion) devices.

Recently Electro-Optical Systems Inc. have released details of a successful cesium ion engine(8) they are also working on the possibilities of a metallic vapour plasma propellant(9) device in which high temperature expansion of plasma, formed by electrically exploding metallic wires and films, has resulted in measurable thrust.

PLASMA—Some Important Contributions

(a) The "Luxembourg Effect" and its Bearing on Recent Plasma Studies and Techniques

In 1933 Prof. Dr. B. D. H. Tellegen(10) of the Philips Natural Science Laboratory at Eindhoven recorded, for the first time, an interaction phenomenon between low frequency radio waves, one of which was beamed by the powerful Radio Luxembourg, the other emanating from Beromünster. The data collected at Eindhoven revealed that the phenomenon had its origin in the transmission between Beromünster and Eindhoven, and it was observed that Luxembourg, Beromünster and Eindhoven were almost co-linearly situated. It was then possible to trace the effect to a region of the ionosphere strongly irradiated by Radio Luxembourg and the effect became known as the "Luxembourg Effect".

A theory explaining this effect (as a non-linear intermodulation effect in the ionosphere) was first proposed by Professor V. A. Bailey and Dr. D. F. Martyn of Sydney University(11). Later Bailey extended this theory to take into account the effect of the earth's magnetic field, leading to the prediction that when the frequency of one of the interacting waves is at, or in the vicinity of, the gyro-frequency of the electrons in the ionospheric region of interest, the wave interaction will be enhanced. This prediction was borne out by direct experimental observations(12).

Later, the simple phenomenon of radio wave interaction was extended to (guided) microwaves propagated in laboratory gaseous plasmas (*under readily controlled conditions*) with a consequent confirmation and generalization of the theory. It thus became possible to develop a method of rather detailed investigation of electromagnetic wave interaction with gaseous plasmas, which in turn enabled a detailed study of the interaction processes taking place among the charged constituents, as well as among the charged and neutral constituents, of gaseous plasmas. In short, microwave diagnostic technique for plasma investigation had been firmly established. Besides this, the non-linear plasma effect observed here has been utilized in several of the non-linear microwave devices described under Artificial Plasmas (section (a)).

(b) Plasma of the Penning Discharge

A common method for the continuous production of plasma utilises the Penning Discharge, a magnetically confined plasma (also termed the Philips Ionisation Gauge, or PIG Discharge) named after the late Dr. F. M. Penning of the Philips Research Laboratories. Originally proposed as an ionisation gauge, it takes place at pressures as low as 10^{-12} mm Hg and it possesses considerable importance in that a Penning "ion-gun" may be constructed to produce a naturally collimated intense ion beam of sharply defined energy(13) (14).

Other means of plasma generation are discussed in reference (1).

Besides Dr. Penning, other workers within the Philips organisation have been actively engaged both in plasma research(15) (16) and engineering. A number of Plasma Torches produced within the Concern will be given in Part 2.

Oskam(15) has investigated the phenomenon of afterglow (i.e., the disappearance of electrons from an isothermal disintegrating gaseous discharge plasma) both theoretically and experimentally, by considering the shift of resonant frequency of a microwave cavity enclosing the plasma. Such items as complex conductivity of a plasma at high frequencies, the influence of the various loss processes on the shape of the afterglow curve, and the connection between plasma conductivity and cavity properties, are treated.

Plantinga(16) has developed an expression for the noise temperature of a plasma using a current-source method, which is valid for any isotropic velocity distribution of the electrons, and for electron collision frequencies that may be dependent on the velocity. Although his work is basically concerned with low temperature, low pressure gas discharges, the treatment is of interest as it concerns the general case where thermodynamic equilibrium does not attain. This leads us to diagnostic techniques.

PLASMA—Diagnostic Techniques

Measurement of parameters(17) such as particle temperature, density and velocity, plays a key role in plasma research. For although it is relatively easy to produce plasma, it is often difficult both to contain it and to understand its properties.

Plasma parameters frequently cannot be measured directly, and are then determined by observing their effects. Hence the term "diagnostic techniques", which can be divided into techniques which disturb the plasma (probes, etc.), and those which do not (spectroscopy, photography, etc.).

Here one should also mention the role of microwaves. Referring back to (a) of the previous section, one can trace the historical basis for scaled down microwave simulation of a non-linear ionospheric (plasma) phenomenon, through to the powerful role currently played by microwave diagnostic technique. In this, plasma perturbation is minimised and plasma contamination avoided. Passive microwave techniques are also possible in which the radiation produced by a plasma is measured.

For those desiring further information on plasma, it should be pointed out that the references given contain extensive bibliographies in themselves. In the second part, to be published next month, some practical plasma devices will be considered.

(This review has been prepared by A. J. Erdman of the "Miniwatt" Electronic Applications Laboratory.)

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DC/AC CONVERTER FOR 20 W FLUORESCENT LAMPS

Transistorised DC/AC converters operating at frequencies considerably higher than that of normal mains can be applied to the operation of fluorescent lamps in caravans, boats, trains and motor vehicles. A unit is described which is designed to operate a standard 20 W fluorescent lamp from a 12 V accumulator supply. The luminous efficiency is high compared with incandescent lamps and the lighting is more uniform. "Flicker" effects are completely eliminated.

The operation of a fluorescent lamp from a low voltage DC supply can be realised in its simplest form by means of a transistorised saturating core converter. The design presented here (which requires no starter) combines simplicity and economy with the advantages of higher frequency operation of the lamp.

Advantages of Operating Fluorescent Lamps at Higher Frequencies

Operation of fluorescent lamps at frequencies considerably above normal mains frequency offers the following advantages:

1. Higher Lamp Efficiency
   Reference to Fig. 1. shows that the efficiency of the lamp rises sharply between 50 and 500 c/s, and again rises appreciably between 2 Kc/s and 10 Kc/s, above which it levels out.

   At sufficiently high frequencies (in Kc/s region) the ionisation in the discharge approaches dynamic equilibrium, resulting in improved lamp efficiency. The behaviour of the lamp then approaches that of a resistive load, the value of which can be considered constant throughout the ionisation cycle. Waveforms also improve, reducing RF interference (see Fig. 3).
2. No visible flicker and no stroboscopic effects.
3. Transformer and ballast choke reduced in size.

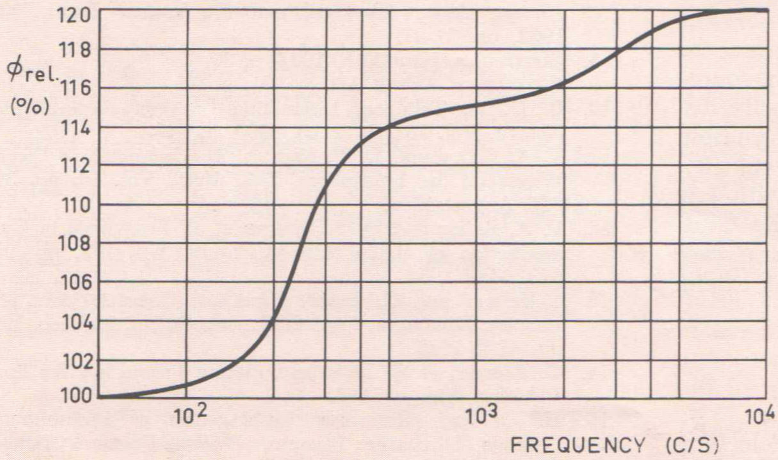


Fig. 1. Variation of relative luminous flux (ϕ_{rel}) with supply frequency, for fluorescent lamp. The value of ϕ_{rel} is taken as 100% at 50 c/s.

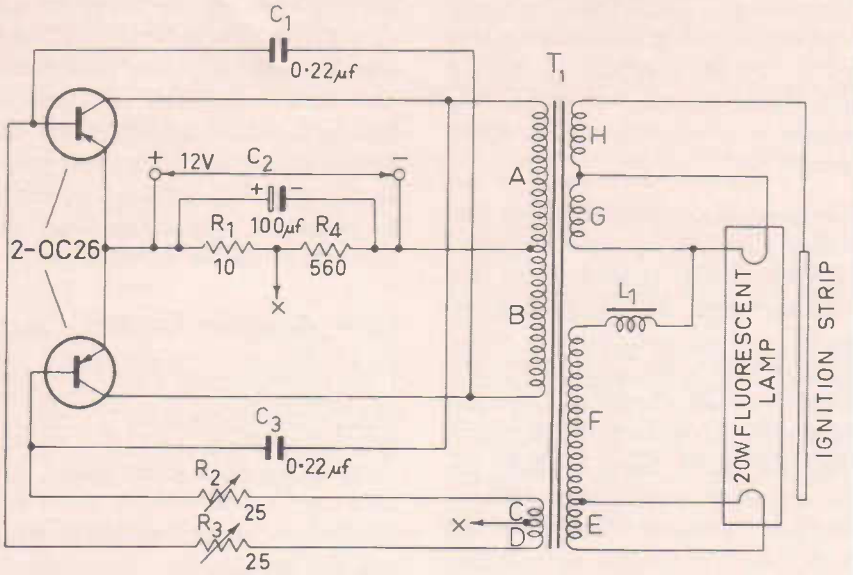
In the design described the operating frequency is approximately 2.3 Kc/s, which represents a good compromise between the advantages listed above and increased transistor switching losses at higher frequencies. The noise produced by the converter (4.6 Kc/s) has been effectively reduced by encapsulating the transformer and choke in specially selected epoxy resins.

Circuit Details (Refer to Fig. 2).

The principle of operation of the saturating core DC/AC converter has been described elsewhere(1)(2). However, several features merit discussion. Starterless operation is generally preferred from the point of view of maintenance. In the circuit to be described the initial striking is effected by an ignition winding (H) which is connected to a metal strip located close to the lamp. The initial heating of the lamp filaments is achieved by the two auxiliary secondary windings (E), (G). This arrangement provides increased applied voltage and filament heating in the "pre-strike" condition, with subsequent reduction once the tube has "struck", due to the inherent regulation of the converter power supply.

A feature of the circuit is regulation of the light output by means of a small ballast choke L_1. Besides limiting the current through the lamp, the choke stabilises this current against variations in supply voltage. For example, as the supply voltage increases, the operating frequency of the converter also increases and increases the impedance of the choke. This change in impedance maintains the lamp current constant for changes in supply voltage between 11 and 13.5 V. Useful light output is maintained at voltages down to about 10 V.

The transistors used in the circuit should be matched pairs (Miniwatt type 2-OC26) for satisfactory operation. The potentiometers R_2 and R_3 in the feedback paths are adjusted (approximately equally) in order to limit the lamp current



Parts List

Component		*Philips Type Number*
1 matched pair of transistors		2-OC26
R_1	10 Ω 5.5 W 5% ww	83540B/10E
R_2, R_3	25 Ω ww pot. (can be replaced by fixed resistors—see text)	E199AA/A25A
R_4	560 Ω 3 W 5%	B8 305 08B/560E
C_1, C_3	0.22 μF 400 V polyester	C296AC/A22OK
C_2	100 μF electrolytic 16 V wkg	C426AM/E100
L_1	Pre-adjusted Ferroxcube ferrite pot-core with coil former	K3.000.80/3B2
T_1	4 Ferroxcube ferrite "E" cores (winding details in text)	56907.36/3A

Fig. 2. Circuit details of DC converter for fluorescent lamps.

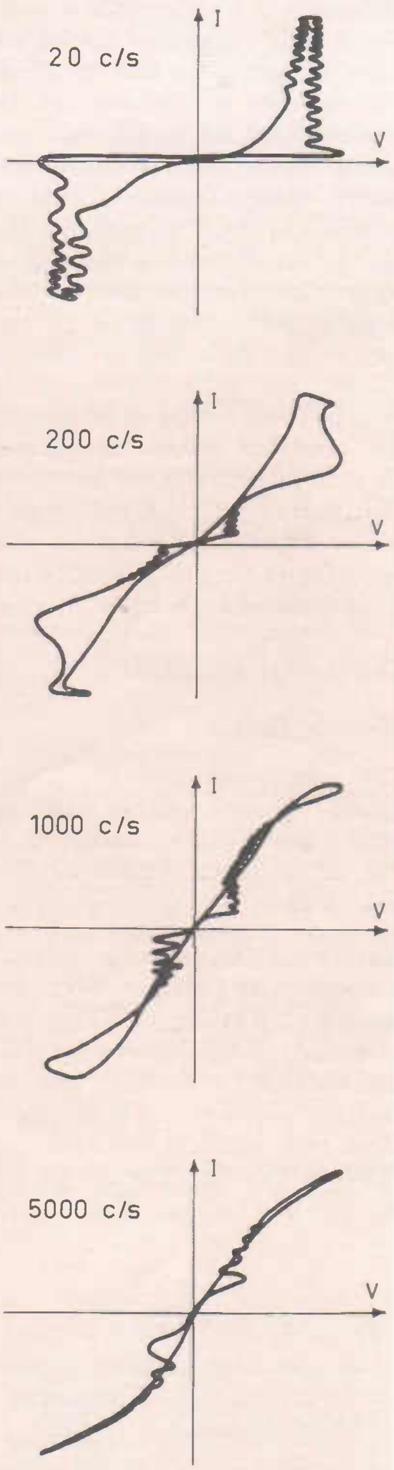


Fig. 3. Current-voltage characteristics of a typical fluorescent lamp, showing how the behaviour becomes more linear at higher frequencies.

to the rated value of 390 mA. With the unavoidable inequalities in collector currents due to the slight differences in transistor characteristics, a noise component having the same frequency as that at which the converter is operating will be produced by the transformer and choke. Ideally, only a double-frequency noise component would be present. In order to minimise the already small noise content, it is advisable to compensate for the slight transistor inequality by setting R_2 and R_3 to slightly different values. The potentiometers could be replaced by fixed resistors once the resistance values are known. In a production run the lamp current should be thus individually set for each unit. The battery consumption of the unit is about 2.6 A for a nominal 12 V input.

Transformer and Choke

Winding Details

The transformer uses Ferroxcube ferrite "E" cores with the windings on a central limb. Referring to Fig. 2, the procedure for winding is as follows:

First wind the primary collector winding (AB) bifilar with the feedback winding (CD), then overwind (EF) followed by (G) and then (H) with .005″ paper insulation between windings. Wire sizes and numbers of turns are listed in Table 1. The air gap between the two halves of the transformer core is 0.1 mm. The choke consists of a pre-adjusted Ferroxcube ferrite pot-core type D36/22N with 0.21 mm air gap. The winding consists of 120 turns of 24 B&S enamelled copper wire which provides an inductance of 10 mH ± 3%.

TABLE 1.

TRANSFORMER WINDING DETAILS

Winding	No. of turns	Enamelled Copper Wire Gauge
A	30	20 B&S
B	30	20 B&S
C	15	25 B&S
D	15	25 B&S
E	15	25 B&S
F	190	25 B&S
G	15	25 B&S
H	600	42 B&S

Encapsulation(3)

As encapsulation technique may be relatively new to those contemplating converter construction, the more important details are included here.

Of the two types of epoxy encapsulants found to be suitable, the first (Epirez 8959) is described by the manufacturers as a "self-impregnating" "flexibilised" epoxy compound and proved satisfactory when cast in a mould of such a size that the unit was completely surrounded by ¼″ of the epoxy compound.

The second compound tested was a low density epoxy compound (Epirez 2255), described by the manufacturers as a "pre-foamed epoxy casting compound", which incorporates microscopically small (.0002″-.0015″ diameter) spheres filled with nitrogen gas. The use of this compound offers further improvement in noise and weight reduction. However, because of the poorer flow properties of this prefoamed compound, the components should first be impregnated using a suitable impregnant (e.g. Epirez 9027—a "one-pot epoxy impregnating compound").

Suitable moulds can be made from metal, rubber or plastic. Polythene is recommended if repeated use of the mould is required. Except for polythene moulds, release agents are necessary to facilitate removal of the hardened casting.

Temperature Range

The striking voltage of fluorescent lamps has a flat minimum value in the vicinity of 20°C, whilst below 5°C and above 60°C it rises considerably. It is this fact which confines circuit operation to within these ambient temperature limits. In addition, when mounted on the recommended heat sink, the transistors are prevented from exceeding their maximum permissible junction temperatures.

In the unit tested, the transistors are mounted with insulating mica washers on the outside of an 18 SWG aluminium box which contained the circuit components. Adequate heat transfer is achieved by providing a cooling area for each transistor of at least 12 sq. ins.

Ignition Strip

The ignition strip, which extends the full length of the lamp, consists of a 20 SWG metallic strip 3″ wide and located ⅜″ from the fluorescent lamp by means of a pair of standard lamp end-fittings: this strip was sprayed with white paint. If a standard industrial type fitting is preferred, the lamp base can then serve as the ignition strip.

Connections and Earthing

It is preferable to mount the unit as close to the supply as possible in order to prevent excessive voltage drop in the connecting leads. The unit can be positively or negatively earthed in regard to the supply, and the ignition strip could also be earthed if desired.

(This investigation was carried out in the "Miniwatt" Electronic Applications Laboratory by A. C. Denne, with acknowledgment to earlier work carried out in overseas Concern laboratories.)

References:

1. W. Elenbaas, "Fluorescent Lamps and Lighting", Philips Technical Library, 1959.
2. G. H. Royer, "A Switching Transistor DC/AC Converter", *Communications and Electronics,* p. 322-324, 1955.
3. Lee & Neville, "Epoxy Resins", McGraw-Hill, 1957.

DESIGN FOR A

Radiation Monitor / Counter

To meet the steady demand for a small inexpensive device to measure or monitor medium levels of radiation intensity, a simple yet reliable circuit has been developed. Such an instrument has applications in prospecting, industrial detection systems or as a safety device in places where radioactive material is handled.

Design Considerations

The circuit (Fig. 5) may be divided into three sections:

- The Geiger-Muller tube which converts the incident radiation into electrical impulses.
- A DC/DC converter to supply the 600 V high tension required by the G-M tube.
- A read-out section which may be either a meter circuit for measuring intensity of radiation or an audio monitoring device.

By the addition of suitable switching, it is possible to provide the alternatives of metering or audio monitoring in the one instrument. A pocket-sized monitor configuration can be easily constructed.

1. The G-M Tube

The advantages of simplicity and low cost make the Geiger tube the obvious choice for a general purpose instrument to measure radiation intensity (i.e., number of incident particles per unit time, rather than energy of the particles). Philips G-M tube type 18503 is a small ($< 2\frac{3}{16}$" × $\frac{11}{16}$" overall) low cost tube, which is sensitive to γ-rays and neutrons. γ-radiation is present in virtually all forms of nuclear decay and has a high penetrating power. Hence the 18503 is ideal as a general detector of radiation. However, if it is necessary to detect α and β radiation as well, the Philips type 18504 may be used directly in place of the 18503 as it has the same dimensions and electrical characteristics.

If a miniature unit is contemplated, the micro G-M tube type 18509/02 ($< 1\frac{1}{2}$" × 9/32" overall) could be considered. However, the plateau range and sensitivity of the 18503 are superior.

The mechanism of the discharge in the G-M tube is such that the incident radiation need only have sufficient energy to liberate an electron from the tube wall or the gas filling to start an avalanche discharge. The magnitude of the discharge depends on the anode supply voltage and the current-limiting resistor, but not on the energy of the incident radiation. A discharge will occur over a wide range of operating voltage Vb (anode to cathode).

Since the 18503 has a wide plateau range (Fig. 1) it is unnecessary to regulate the HT supply. The supply unit without regulation delivers a DC voltage ranging from 360 V to 620 V over a wide range of battery voltage, temperature and transistor parameter variation, this range being quite suitable for the 18503 operation.

The slope of the plateau is a function of the anode load resistor (R_a) and stray-anode-ground capacity. If C_{stray} is large, multiple discharges will take place for each incident particle. Thus to maintain accurate counting at high anode voltages, C_{stray} must be kept to a minimum.

The form of the discharge current pulse in the G-M tube is shown in Fig. 2. Reduction of R_a below 10M Ω would increase this current (and lengthen the plateau), but would seriously affect the life of the tube.

2. DC/DC Converter

The DC converter is of the ringing-choke type, the operation of which has been treated previously⁽¹⁾. The design given here is a compromise involving size, cost, ease of construction of the transformer, and stability of output voltage and battery drain with variation in battery voltage and temperature. Thus a design requirement was that the smallest possible pot core be used, but at the same time the secondary must have a usable wire size. In practice, the completed transformer is less than ¾" diameter and ½" high. The converter operates at a frequency of 11 Kc/s.

The capacitors in the voltage-doubler must be large enough to maintain the supply voltage when the G-M tube discharges ($I_{peak} = 40$ μA).

PERFORMANCE SPECIFICATIONS

Battery voltage	9 V to 5.5 V (end-of-life)
Battery current	6 mA avge. (with meter circuit) 5 mA avge. (with audio monitor)
Supply voltage to G-M tube	600 V (refer text)
Range of ambient temperature for reliable operation	0°C to + 55°C
Accuracy of indication (meter circuit) ..	better than 10%
Maximum count rate	1500 counts/sec. ≡ 75 mr./hr. (calibration applying for 18503 using substantially γ source)

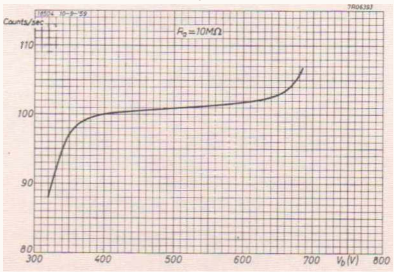


Fig. 1. Plateau of the 18503 counter tube.

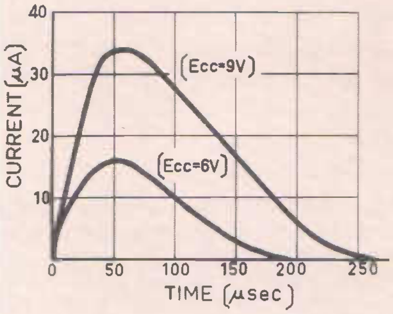


Fig. 2. Waveform of current pulse in G-M tube (Ecc is battery voltage).

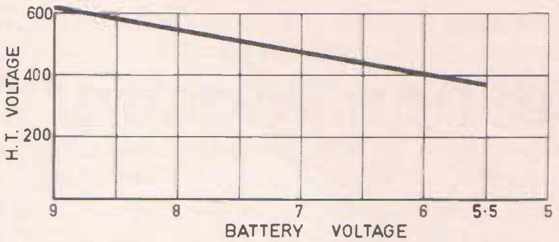


Fig. 3. Variation of HT voltage with battery voltage.

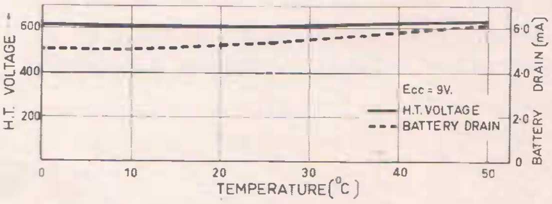
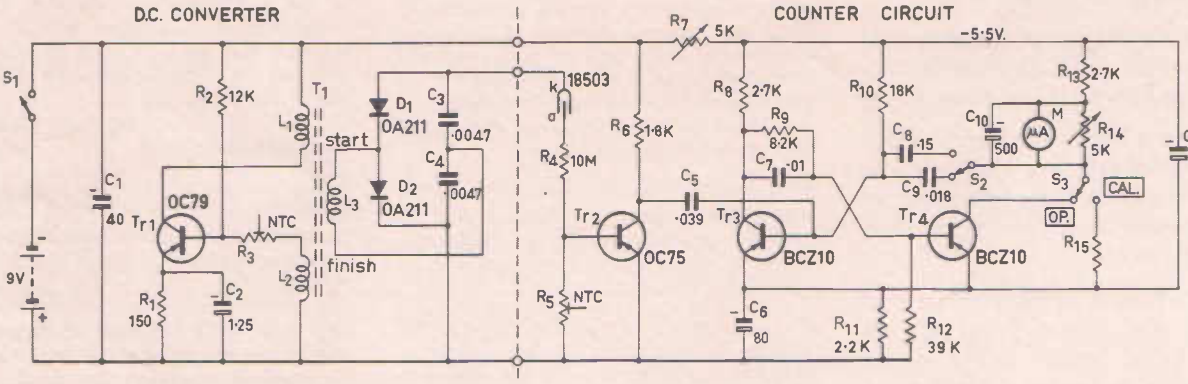
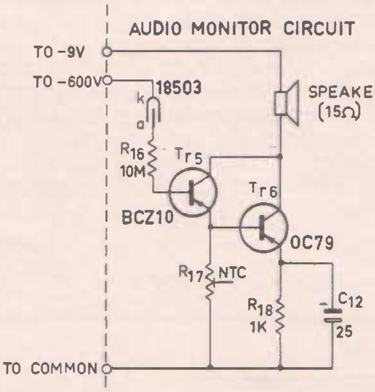


Fig. 4. Variation of battery drain and HT voltage with ambient temperature.





R_1	150 Ω
R_2	12 KΩ
R_3	NTC, 150 Ω at 25°C
$R_{4, 16}$	10 MΩ
$R_{5, 17}$	NTC, 4.7 KΩ at 25° C
R_6	1.8 KΩ
R_7	5 KΩ, lin. (Philips EO98CG/6OE03)
$R_{8, 13}$	2.7 KΩ, ± 5%
R_9	8.2 KΩ
R_{10}	18 KΩ, ± 5%
R_{11}	2.2 KΩ
R_{12}	39 KΩ
R_{14}	5 KΩ preset (Philips EO97AA/5K)
R_{15}	(37,500 Ω minus R meter) ± 1%
R_{18}	1 KΩ

All fixed resistors ½ W, 10% cracked carbon, except where otherwise stated. (Philips B8 305 05 range)

NTC resistors all Philips B8 320 07P range.

Tr_1, Tr_6	OC79
Tr_2	OC75
Tr_3, Tr_4, Tr_5	BCZ10
D_1, D_2	OA211
G-M Tube	18503
M	meter, 250 μA FSD, 200 to 600 Ω (refer text)

C_1	40 μF, 16, VW, electrolytic
C_2	1.25 μF, 16 VW, electrolytic
$C_{3, 4}$	.0047 μF, 400 V, polyester
C_5	.039 μF, 125 V, polyester
C_6	80 μF, 6.4 VW, electrolytic
C_7	.01 μF, 125 V, polyester
C_8	.15 μF, 5% (for 0 to 150 scale)
C_9	.018 μF, 5% (for 0 to 1500 scale)
C_{10}	500 μF, 4 VW, electrolytic
C_{11}	40 μF, 16 VW, electrolytic
C_{12}	25 μF, 4 VW, electrolytic

All electrolytic capacitors Philips range C 426.

All polyester capacitors Philips range C 296.

T_1	Ferroxcube ferrite pot core type D18/12–3B3 (no air gap)
L_1	60 turns of 33 B&S enam. copper
L_2	12 turns of 35 B&S enam. copper
L_3	1750 turns of 40 B&S enam. copper

Fig. 5. Circuit Details of Radiation Counter or Monitor.

Under no-signal conditions then, the capacitors charge to the peak value of the secondary voltage and very little secondary current flows. Because of this, the primary waveform is not the ideal square-wave, but more like a half-rectified sine wave.

To reduce the effects of change in current gain and I_{CBO} (between different transistors and with temperature) and to ensure starting down to O°C, an emitter resistor is used which is partially bypassed by C_2, and an NTC resistor is used in the base circuit.

The variation of HT voltage with battery voltage and temperature, together with battery drain versus temperature is given in Figs. 3 and 4. From the point of view of insulation, the secondary (wound on first) must be connected to the voltage doubler as indicated in the circuit diagram.

3. Counter Circuit

The counter circuit consists of a monostable multi-vibrator(2) which is triggered by the (amplified) pulses from the G-M tube. A large integrating capacitor (C_{10}) has been used, and to damp residual meter fluctuations a slightly over-damped meter movement has been chosen. Thus a fairly steady reading results despite the random timing between input pulses. Being in the collector of the normally OFF transistor, no current flows in the meter when there is no incident radiation.

The choice of the silicon transistor type BCZ10 for this application was dictated by the fact that for reliable operation of the multivibrator, the collector current of the ON transistor should be made $> 25\ I_{CBO}$(3) at the maximum temperature of operation. The BCZ10 is the cheapest available transistor that will allow reliable operation with a collector current of 1 mA or less.

Provision has been made for maintaining the supply to the multivibrator constant at 5.5 V. Thus the multivibrator delivers constant amplitude and width pulses to the meter circuit, which then yields an accurate indication of count rate.

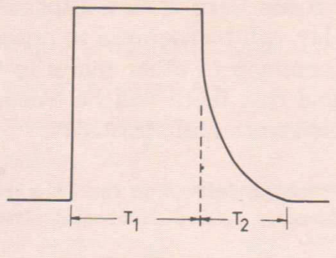


Fig. 6. Collector current waveform in T_{r4} (see text).

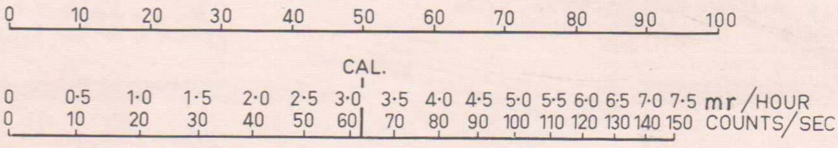


Fig. 7. Comparison of linear scale with corrected scale, showing CAL position (calibration in mr/hr is for 18503).

For *initial* calibration, with S_3 in the calibration position, R_7 is adjusted so that the multivibrator supply voltage is 5.5 V (using an external voltmeter). The pre-set potentiometer R_{14} is then adjusted for half-scale deflection on the count-rate meter (the CAL marking on the meter scale in Fig. 7). Succeeding adjustments (as the battery voltage drops) are made by setting S_3 in the CAL position and adjusting R_7 for half-scale deflection on the count-rate meter. If half-scale deflection cannot be obtained, the battery must be replaced.

The minimum pulse amplitude required from the G-M tube for triggering is 12 μA, and Fig. 2 shows that this value is exceeded (when $E_{CC} = 9V$) for 160 μsec. Hence the multivibrator ON time must be $>$ 160 μsec. for reliable operation, and it was found that with a multivibrator pulse width of 200 μsec. the operation was virtually independent of the widths of triggering pulses up to 160 μsec. duration. In the actual circuit, the multivibrator pulse width (T_1 of Fig. 6) is 220 μsec. for the (0-1500) cts./sec scale and 2.2 msec for the (0-150) scale. However, the decay time (T_2) of the collector current pulses through Tr_4 (as shown in figure) is 180 μsec. and 1.8 msec for the two scales respectively.

When the transistor has been triggered, a second pulse occurring within the time ($T_1 + T_2$) will not be counted. Thus the total "dead time" (T) for the counting circuit is 400 μsec for the 0-1500 scale and 4 msec for the 0-150 scale.

For all devices counting pulses of a random nature, there is an inherent error involved which is a function of the "dead time" of the counting circuit. It can be shown that the percentage error in counting is given by:

$$E = \frac{n_o\ T \times 100}{1 + n_o\ T}\ \%$$

where n_o = number of random incident pulses per unit time

T = dead time of counting circuit

Thus for example if $n_o = 1000$ pps and $T = 400$ μsec. or if $n_o = 100$ pps and $T = 4$ msec, $E = 28.6\%$ in each case, i.e., the counter will read 28.6% low in both cases. This error can be corrected by the meter scaling. The calibrated scale is shown in Fig. 7 together with a linear scale for comparison.

With this correction applied, the count-rate error depends largely on the time-constant circuits $R_{10}\ C_8$ (or $R_{10}\ C_9$) and R_{15} the calibrating resistor for the multivibrator supply voltage.

4. Audio Circuit

This circuit, generally known as the Darlington compound or "Super alpha transistor", has the advantage over a normal two-stage collector-coupled circuit when used in pulse applications in that both transistors are switched off when no signal is applied, so the current drain is minimised. However, leakage current in the first stage is amplified in the second stage, so for low current operation a transistor with very low I_{CEO} must be used in the first stage. It is for this reason that the silicon transistor type BCZ10 is used, which incidentally is comparable in price to similar germanium types.

There still remains the problem of leakage current in the OC79. This is minimised by the NTC resistor R_{17} and R_{18}. At 50°C, the total current is less than 200 μA for an OC79 with high I_{CBO}. Using a 2" speaker with a 15 Ω voice coil as the collector load, the output pulses are clearly audible with the battery voltage down to 5.5 V, even when minimum β transistors are used.

(This article is based on work carried out in the "Miniwatt" Electronic Applications Laboratory by N. A. Steadson, with acknowledgment to earlier work carried out in overseas Concern laboratories.)

References

1. The Design of Transistor DC Converters, *Electronic Applns.*, Vol. 16, (1955/56) No. 2, pp. 59-79).
2. P. A. Neeteson, Junction Transistors in Pulse Circuits, Philips Tech. Library, 1959.
3. E. Wolfendale, The Junction Transistor and Its Applications, Heywood & Co. Ltd., London, 1961.
4. K. W. Cattermole, Transistor Circuits, Heywood & Co. Ltd., London, 1959.

Leaves from the Laboratory Notebook

Delayed Operation of Relays Using NTC Resistors

In many electronic and electrical circuits a minimum time delay is required between the switching of different circuits, such as the application of filament and HT voltages to transmitting tubes, the switching of different motors in a given sequence or the switching of advertising illumination. Where precision of the timing is not of prime importance, the combination of one NTC resistor with a suitable relay provides a simpler and less expensive circuit than an elaborate electronic timer or even a bimetallic relay.

When current is passed through a negative temperature coefficient (NTC) resistor, the resulting power dissipation will heat the resistor causing a decrease in its resistance until an equilibrium condition is reached.

If a relay coil is connected in series with the resistor, the current through the circuit will slowly rise from an initial value, determined by the relay resistance and the cold resistance of the NTC to a final value determined by the relay resistance and the hot resistance of the NTC. The time taken for the current to reach its equilibrium value is mainly a function of:

supply voltage.

relay resistance.

the particular NTC resistor used.

Additional factors which influence the time are:

variations in ambient temperature.

fluctuations in supply voltage.

circulation of air in the vicinity of the NTC resistor.

Due to the above factors and the effect of cumulative tolerances, the relay pull-in current should be specified so that it is not too close to the initial current (which may result in premature operation), nor too close to the equilibrium current (which may result in failure to operate). The circuit of Fig. 1 is suitable for the operation of DC relays. When the relay operates, the NTC resistor is short-circuited by one set of contacts, thus allowing it to cool in readiness for a further operation. If the rest time between operations is less than, say one minute, the NTC resistor will not have cooled sufficiently and the subsequent delay will be shorter than normal.

An improvement on the circuit of Fig. 1, allowing for adjustment of the delay time, is shown in Fig. 2. The variable resistor R_1 is used to adjust the delay time, while R_2 provides a limiting value which ensures that the dissipation limit of the NTC resistor is not exceeded.

In the table accompanying the circuit of Fig. 2, suitable combinations of NTC resistor and relay are listed for a number of commonly-used relay supply voltages.

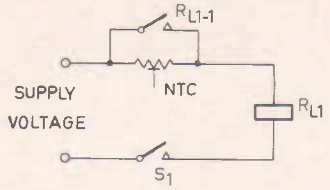
It should be noted that the table has been compiled as a guide to the circuit designer and, due to the number of variables mentioned above, should be used as a starting point in the choice of suitable values rather than as a final design. It has been assumed that normally the time-delay relay will be required to operate from a supply voltage common to other relays in the circuit or installation, and that there will be freedom of choice in the relay resistance and sensitivity.

(*This article is based on work carried out in the "Miniwatt" Electronic Applications Laboratory by D. J. Hancock.*)

Reference

1. H. Linau and I. Seifert, Relay Time Delay Circuits with NTC Resistors, *Matronics*, No. 12, April 1957, p. 216.

Fig. 1. Details of simple time delay.



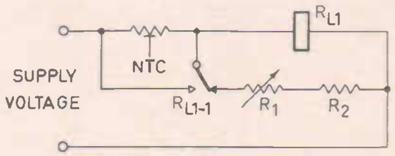
S_1 = Main switch.

R_{L1-1} = Shorting contacts allowing NTC resistor to cool between operations.

Supply voltage	50 V	50 V	50 V
NTC Resistor	B8 320 07P /4K7	B8 320 07P /4K7	B8 320 07P /4K7
Relay Resistance	1500 Ω	2500 Ω	2000 Ω
Pull-in current	25 mA	15 mA	20 mA
Time Delay	10 secs	15 secs	20 secs

N.B. Time delay is approximate only and will depend on ambient temperature and air circulation.

Fig. 2. Details of adjustable time delay.



Supply Voltage	6 V	12 V	24 V	50 V
NTC Resistor	B8 320 07P /150E	B8 320 07P /150E	B8 320 07P /1K5	B8 320 08P /4K7
Relay Resistance	100 Ω	220 Ω	2700 Ω	3000 Ω
Relay Pull-in Current	5 mA	5 mA	5 mA	5 mA
R_1 (variable)	100 Ω	500 Ω	5000 Ω	2000 Ω
R_2 (fixed)	10 Ω	200 Ω	1000 Ω	500 Ω
Range of Delay Time	3-50 secs	5-50 secs	5-60 secs	0-30 secs

N.B. Time delay setting will vary with ambient temperature and air circulation.

Data on Suitable NTC Resistors

	Philips Type B8 320 07P/150E	Philips Type B8 320 07P/1K5	Philips Type B8 320 08P/4K7
Resistance at 25°C (R_{25})	150 Ω ± 20%	1500 Ω ± 20%	4700 Ω ± 20%
Maximum dissipation at 25°C amb. (W_{max})	0.6 W	0.6 W	1.8 W
Resistance at W_{max} (25°C amb.)	30 Ω	80 Ω	80 Ω
Current at W_{max} (25°C amb.) ..	140 mA	85 mA	150 mA
Dissipation constant at 25°C* ..	4.5 mW/C°	4.5 mW/C°	13 mW/C°
Maximum temperature	150°C	150°C	150°C
Recovery time†	20 sec.	30 sec.	90 sec.

* Dissipation constant is the power that causes a rise in temperature of 1C°. This constant may be used to determine the temperature rise of an NTC resistor at a given dissipation.

† Recovery time is the time to reach half the R_{25} value (if the NTC, which had been operated for some time at W_{max}, is cooling in still air at 25°C).

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