# Research and Philips

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Natuurkundig Labaratorium der N.V. Philips Gloeilampenfabrieken, Eindhoven

Mullard Research Laboratories, Redhill, Surrey, England

Les Laboratoires d'Electronique et de Physique Appliquée, Limeil-Brévannes, France

Philips Zentrallaboratorium, G.m.b.H., Aachen and Hamburg, Germany

M.B.L.E. Research Laboratory, Brussels, Belgium

Philips has always been concerned with new things. It began as an incandescent lamp factory when lighting was in its infancy. Today, although it proudly bears its original name, Philips' Gloeilampenfabrieken (Philips incandescent lamp works), it is active in nearly all branches of electronic and low power electrical engineering and it has pioneered in many. The incandescent lamp was the first example of an electrical device finding its way into the average home. Also in later years the company has been prominent in fields that influence the daily life of normal citizens, including street lighting, telephone equipment, broadcasting stations and public address systems. But other subjects were by no means neglected and there has been considerable activity in X-ray equipment, measuring instruments, radar and scientific instruments. A computer division was started only recently but components and subassemblies for computers have been marketed for years.

In a company that owes it very existence to technical progress and innovation, research must needs play an important role. This was realised from the start by the founders of the company, Gerard and Anton Philips. In 1914 they appointed Dr.Gilles Holst as their director of research and he brought into being a vigorous research group that soon obtained an excellent reputation and made important contributions to basic science, technology and product design. Today the Eindhoven Laboratories with a total personnel of over 2000 and an academic staff of about 400 are still the main centre of research in Philips.

As the company grew its structure was modified. Gradually there evolved a pattern of a world-wide federation of industries held together by a central organization.

In many countries members of the Philips group make important contributions to the economical and technical life of the nation and are called upon to render services to their respective governments. Therefore it is not surprising that in matters of research they do not want to depend exclusively on the Eindhoven laboratories but require organizations of their own to advise management, assist factories and carry out work for the government. As a consequence there came into being laboratories in France, England, Germany and Belgium. All these laboratories report to the management of their national organization but they have full access to patents and to technological skill and scientific knowledge available in the company as a whole and administrated by the Eindhoven centre. In matters of national interest the management in the respective countries is at liberty to use

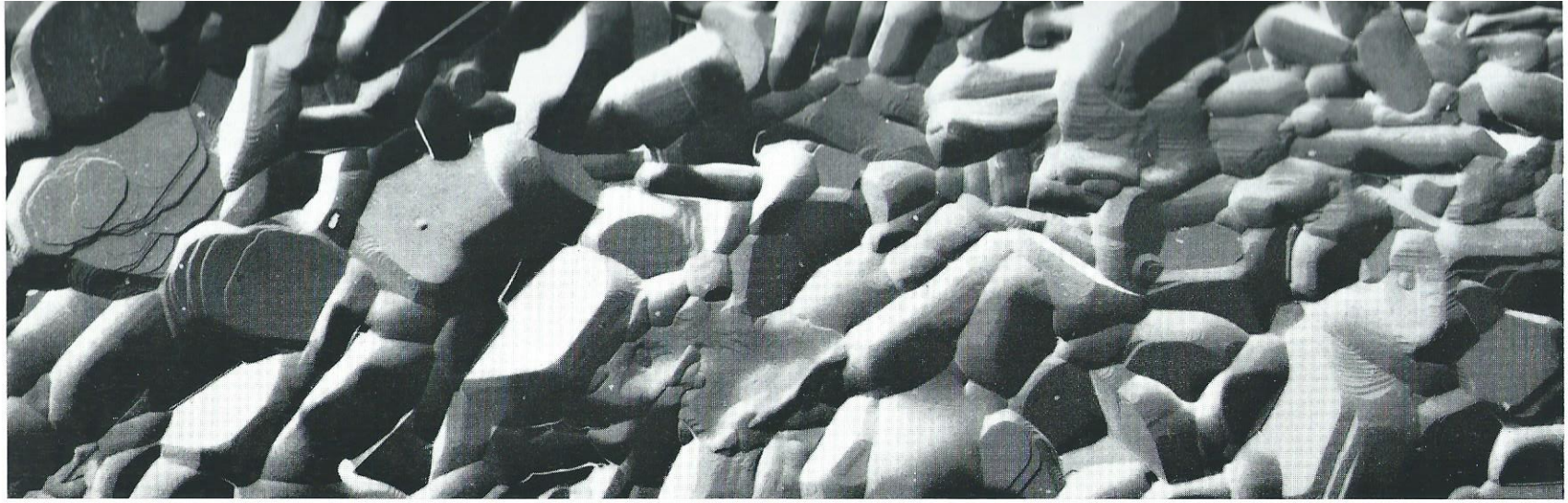
such knowledge as it sees fit, but unless there are cogent reasons that dictate otherwise the laboratories keep each other informed about programmes and progress. The main lines of programmes are discussed at regular meetings of research directors. Frequent meetings and seminars ad hoc as well as personal visits ensure sufficient contact and avoid useless duplication especially in those cases where it has been found desirable or unavoidable that several laboratories work in the same field. In this way national requirements with respect to independence and security are fully met, but each laboratory can fulfill its tasks far more efficiently than if it were entirely on its own.

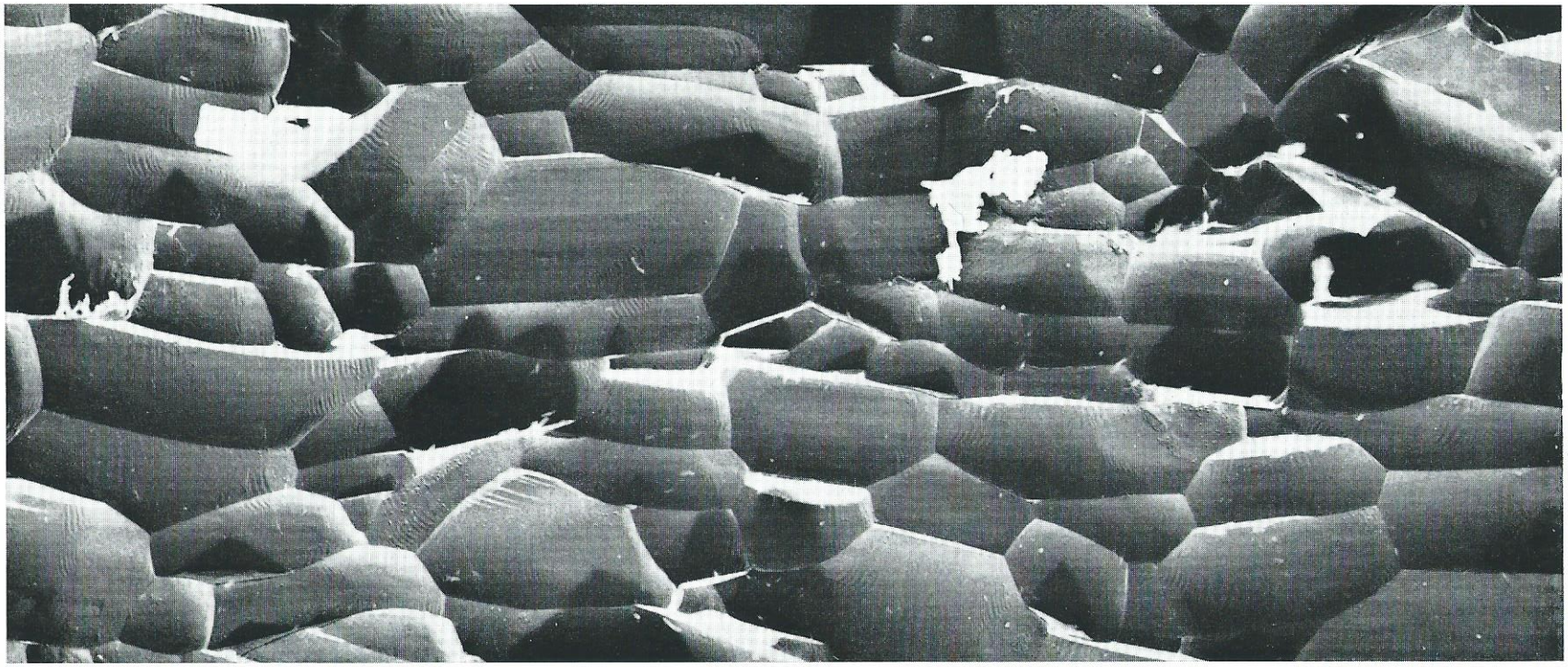
At the same time the existence of research groups in several countries is an important asset to Philips as a whole, not only because of the added manpower – the total personnel of all the research groups outside the Netherlands is roughly equal to that of the Eindhoven laboratories – but especially as a safeguard against mental inbreeding and scientific provincialism.

In the following pages we try to convey an idea of the facilities, character and achievements of this research potential.

# Philips' Natuurkundig Laboratorium Eindhoven

One of the most notable characteristics of the Philips Research Laboratories (officially: Natuurkundig Laboratorium der N.V. Philips' Gloeilampenfabrieken) with their record of more than fifty years of ever increasing activities and broadening tasks is the great variety of fields in which they are active.
Immediately after their foundation, the laboratories concentrated on the physics and chemistry of the incandescent lamp, but it was not very long before they entered the field of gas discharges. The subsequent widening of their scope has mostly gone hand in hand with the promotion of new industrial activities of the Philips Concern and has put the scientific activities on their present broad foundation.
As examples of these activities we might mention mechanical technology at one end and biology at the other with, in between, such things as magnetism and semiconductor physics, radio, television and microwave techniques, mathematics and computer technique, photochemistry, vacuum technique and plasma physics.
Research laboratories combining such widely varying scientific disciplines and branches of specialist knowledge offer far greater possibilities for cross-fertilization between disciplines than development laboratories concentrating on a limited group of products. We might illustrate this by mentioning the Plumbicon, the television pick-up tube which grew out of contacts between the groups working on semiconductor physics, vacuum tube techniques and television systems. Another example is in digital control of machine tools which resulted from cooperation between specialists in mechanical technology and in electronics, and to which the optics group contributed a precision digital measuring system. Thirdly, our research into magnetism could only result in industrial activity on the basis of fundamental knowledge of technological processes, such as that of sintering.
Since 1914 the site of the laboratory buildings has formed part of the factory area, but now the Laboratories are in the process of being transferred lock, stock and barrel (or might we more aptly say: plug, pump and sliderule?) to a new site on the perimeter of the town of Eindhoven. The new buildings give visible expression to the determination of the company to provide its research staff with the most up-to-date facilities. The larger part of the buildings has a layout fit for universal use, i.e. equally suitable for electronic, electromechanical, physical and chemical research. This is a logical consequence of the need for adaptability to a great variety of activities.
Of this variety we hope to give some illustration in the pages which follow.



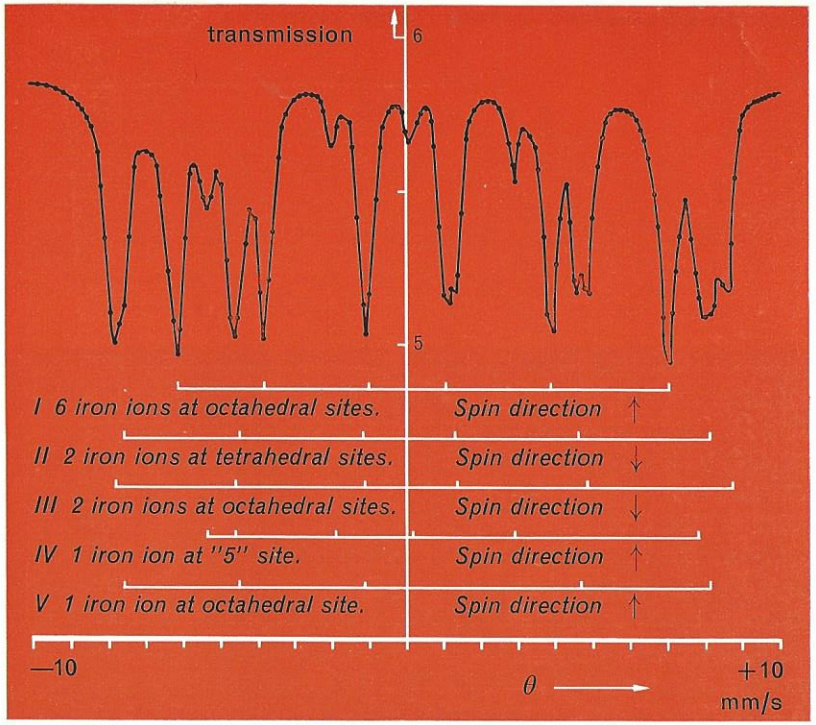


2 μm

*1*
*Electron microscope photograph of nonoriented ferroxdure particles.*
*1 cm on the photograph is 1 μm.*
*2*
*Electron microscope photograph of ferroxdure particles with approximately parallel orientation of the hexagonal axes.*
*1 cm on the photograph is 1 μm.*

# Ferroxdure

A new permanent magnet material, ferroxdure, discovered in the Philips Research Laboratories in 1950, has since found greatly varied and very extensive technical application. With the basic chemical composition Ba $Fe_{12}O_{19}$ and a hexagonal crystal structure, the material shows strong magnetic anisotropy, magnetization being very strongly coupled to the hexagonal axis.
Owing to the very extensive fundamental knowledge on magnetic materials available in the Laboratories, the basic findings on ferroxdure could be made to result in its large scale production in a relatively short period. Studies on the mechanisms of magnetization processes had shown that very small particle size, of about one micron, is essential to obtaining permanent magnet materials. By using advanced ceramic techniques we succeeded in sintering these particles to a compact body while keeping the grain size small, and thus in retaining the good magnetic properties.
Measurements on the magnetic anisotropy of single crystals gave the clue to a technique for giving the particles a parallel orientation before sintering the compact. This raised the maximum magnetic energy available in a permanent magnet considerably. In laboratory samples about 87% of the theoretical maximum value was obtained: $(BH)_{max} = 5.10^6$ gauss oersted, as compared with the value of $1.10^6$ gauss oersted holding for a material with random spatial orientation of the crystallites.
Fig.1 is an electron microscope photograph of this material with random orientation. In the photograph of fig.2 the hexagonal axes have been given an approximately parallel orientation. The crystallites are platelets with the preferred direction of magnetization perpendicular to the main plane.
Notwithstanding the complexity of the crystal lattice, in which the trivalent iron ions occupy five magnetically nonequivalent sites, the value of the magnetic moment at 0° K could be precisely predicted.
In these calculations our studies of antiferromagnetic interactions in oxides have stood us in good stead. As a result of these interactions not all magnetic moments point in the same direction. Because of the difference in occupation of the various lattice sites, a net magnetic moment results.




In an attempt to understand the large magnetic crystal anisotropy, calculations were made, based on pure dipole-dipole interaction between the magnetic iron ions. These, in fact, indicated a large anisotropy.
Recently we have acquired a deeper insight into the properties of ferroxdure by making use of the Mössbauer effect which enables the internal magnetic fields to be measured from small splittings and shifts of the nuclear levels of the $Fe^{57}$ isotope. These effects are caused by the local values of the magnetic field, the electric charge and the electric field gradient at the site of the iron nuclei.
As a matter of fact, the Mössbauer spectrum of the $BaFe_{12}O_{19}$ compound can be explained as a superposition of the subspectra of the iron ions in the five different lattice sites (see fig.3). All sublattice magnetizations prove to be parallel to the hexagonal axis (some are antiparallel) and to contribute to the crystal anisotropy. The magnitudes of the dipole-dipole fields appear to be consistent with the calculations mentioned above.
We have been able to determine the dependence of the sublattice magnetizations on temperature. Taking into account the value of the net magnetic moment at 0° K and the known spin ordering, this yields a full explanation of the dependence of the overall magnetization on temperature.

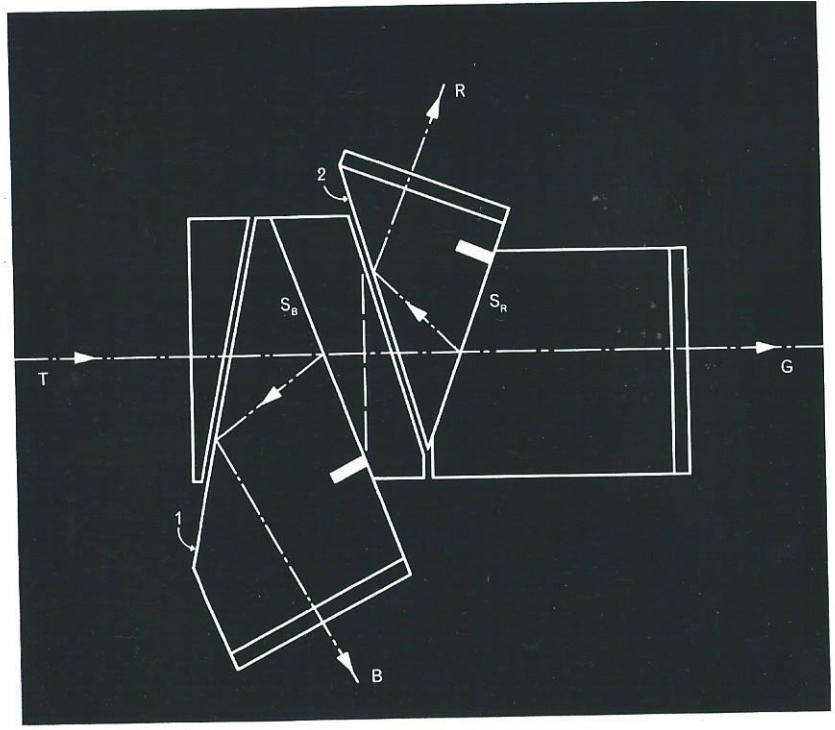
# Colour separation in television cameras

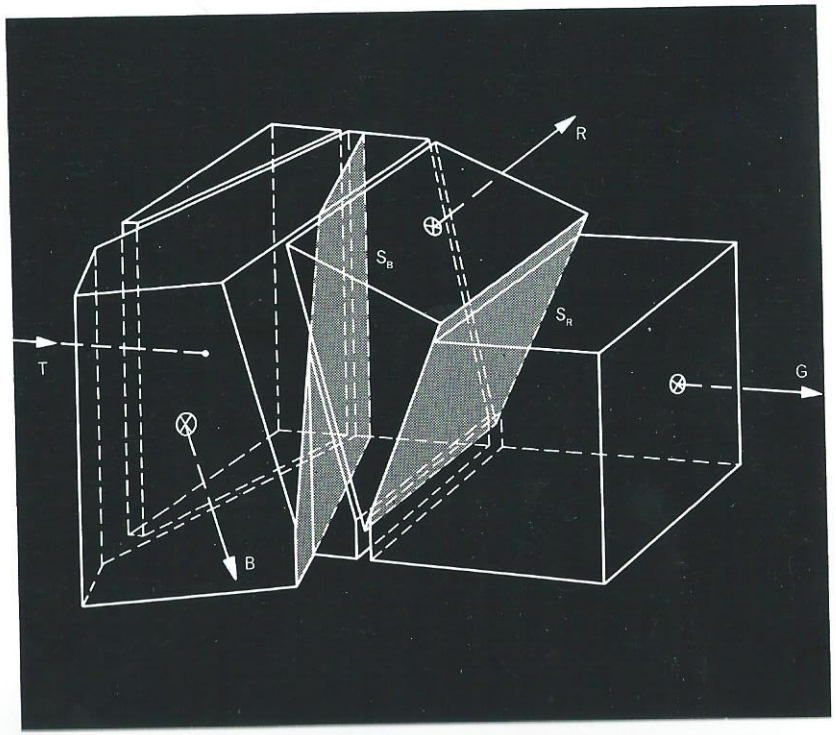
Cameras for colour television broadcasting must possess powers of colour discrimination matching those of the human eye. Essentially, they consist of three cameras, each having their own spectral sensitivity distribution curve with the peak in the blue, green and red respectively.

After passing through the objective lens, the blue, green and red components of the light from the scene to be transmitted must be separated and guided to three identical pick-up tubes via three optical channels having specified transmission characteristics. In order to avoid parallax phenomena, the three coloured images must appear to be seen from the same point, i.e. have a common entrance pupil.

In the design of a colour separation system, account had to be taken of the fact that 'Plumbicons' were to be used for image pick-up. These tubes not only have outstanding colour sensitivity, but they are of a compactness comparable to that of the objective lenses. Therefore, the colour separation system had to meet very high demands as to quality and compactness. In particular, variations in colour intensity across the image tube had to be kept within very close limits, and polarization effects resulting in changes in colour rendition had to be avoided.

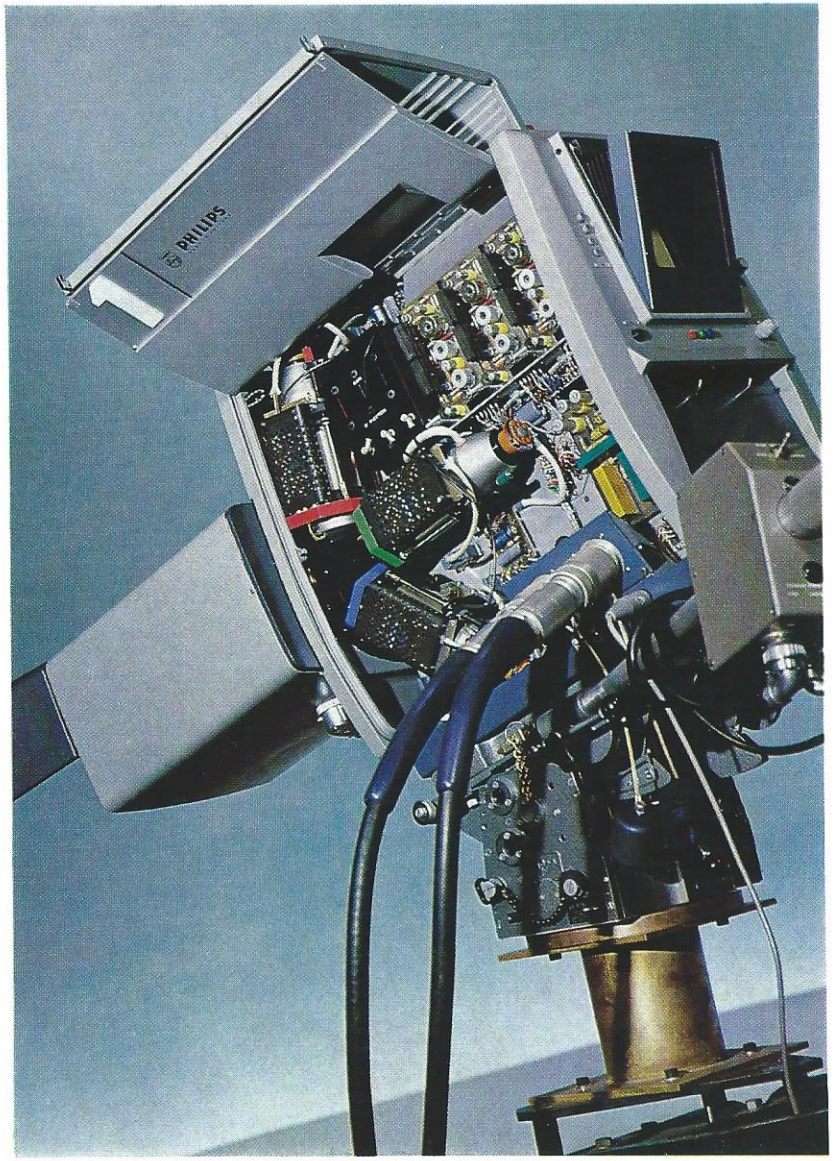
For separation, use is made of colour-selective interference filters having the property of reflecting a predetermined part of the spectrum and transmitting the complementary part. Such filters consist of a number of very thin transparent layers of alternatingly high and low refractive index, deposited on a glass surface by evaporation in vacuo. In our device the glass surfaces are those of a prism system. A number of such systems were designed and one of them is shown in fig.1. The colour-selective interference layers are at $S_B$ and $S_R$, where the faces of the prism sections are cemented together so as to protect the layers against the influence of dust and moisture. In order to keep the angle of incidence on the interference filters as small as possible, thin air layers are provided that cause total reflection of the blue and red rays at faces 1 and 2, respectively. The green rays pass straight through the system. For each of the coloured beams the system behaves as a plane-parallel plate placed at right angles to their optical axis. Before leaving the system, each component passes through an absorption




*1*
*Schematic diagram of a prism system for colour separation in a television*

filter which is cemented on to the prism and removes any unwanted wavelength that might still be present.
The actual form of the prism system is that shown in fig. 2, where the part on the right-hand side of the vertical dotted line in fig. 1 has been rotated 90° with respect to the part on the left. The shaded faces carry the interference layers. In this compact design special precautions had to be taken against glare due to spurious reflections.
Fig. 3 shows the interior of a colour television camera. The colour separation system is located in the small space between the objective lens and the pick-up tubes.




*3*
*View of the interior of a colour television camera. The colour separation system is placed between the objective lens and the pick-up tubes.*

*4*
*Colour separation by a prism system.*

With printed wiring, photomechanical production processes such as photo-etching and photo-electroforming were introduced into electronics. They gave miniaturization a start and have led to partially or completely integrated circuits (thin film and crystal circuits). In these photo fabrication techniques, photomasks are indispensable; they are microphotographic negatives or positives, usually containing a large number of identical patterns that must have high contrast and high definition. Application to very high frequencies has led to a demand for ever finer patterns and has prompted this laboratory to investigate the limitations of photographic materials.

Although the well-known Lippmann emulsions have very fain grain, light entering them is subject to a certain amount of scattering. Moreover, the emulsion must be put on in a layer of about 6 $\mu$m thickness if it is to contain sufficient image-building metal. Since objectives with relatively high aperture must be used, light penetrating into the layer spreads into a cone, and because the layer absorbs no more than 50% of the incident actinic light, some image spread results. Our search has been for a very thin layer without any grain in which the photosensitive compound would be present in molecular dispersion and which would have relatively strong absorption (e.g. 50% per $\mu$m). However, the photographic sensitivity of such a layer is inherently low, because at least one photon must be absorbed for the formation of one molecule of the image-forming substance. By contrast, in a silver halide emulsion the absorption of a few photons suffices for the reduction of an entire grain of silver halide in the later process of development.

To compensate for this low sensitivity, we have worked for a system permitting the products of the light reaction to be converted into intensifiable latent metallic images by secondary reactions such as: $Ag^{+}$ + red. $\rightarrow$ Ag + ox., and $Hg_2^{++} \rightarrow Hg^{++}$ + Hg.

In this choice we have been guided by our experience with a chemical method of intensification, known for long as 'physical development'. For this method we had already worked out developers for the selective deposition of Hg, Au, Pt, Pd, Cu, Ni, Sn, Pb, and In while, especially for Ag, very stable and yet very active developers could be composed. Our investigations have resulted in a group of photographic systems





knew the art of talking man to man, even when addressing a vast audience. Those who knew him best were aware that he expressed the feelings that ruled his daily actions and were the source of the good advice which permeated his words of thanks and his remarks in general.

To the younger members of the audience, Philips said, 'When, after having reached some conclusion, you find that someone else has a better idea, don't be headstrong; never think of opinions as a matter of prestige. It is better to turn back half way than to persist on a wrong course.'

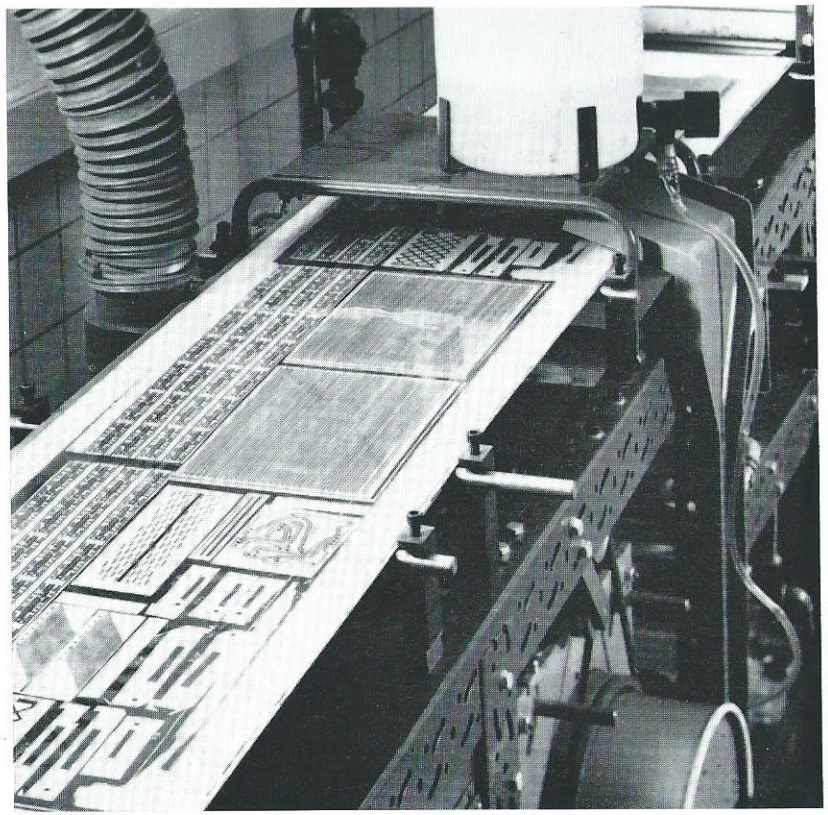
This was a principle to which Philips had always adhered to the best of his ability: to accept advice, to listen, to take note of changing circumstances, and thus to retain the flexibility to change course in time, in short the policy of rapid adaptation so valuable to a leader. He had always been aware of the danger of professional blindness, as we have noted earlier, and he felt that it was to his wife, whose strong common sense had proved so valuable, that he owed his preservation from it. His audience found his grateful references to his wife profoundly moving.

After her husband had spoken, Mrs Philips voiced her own feelings, 'I have had the privilege to be the daughter of a great man, and on a day such as this I feel I can say that I have also the privilege to be the wife of a great man.

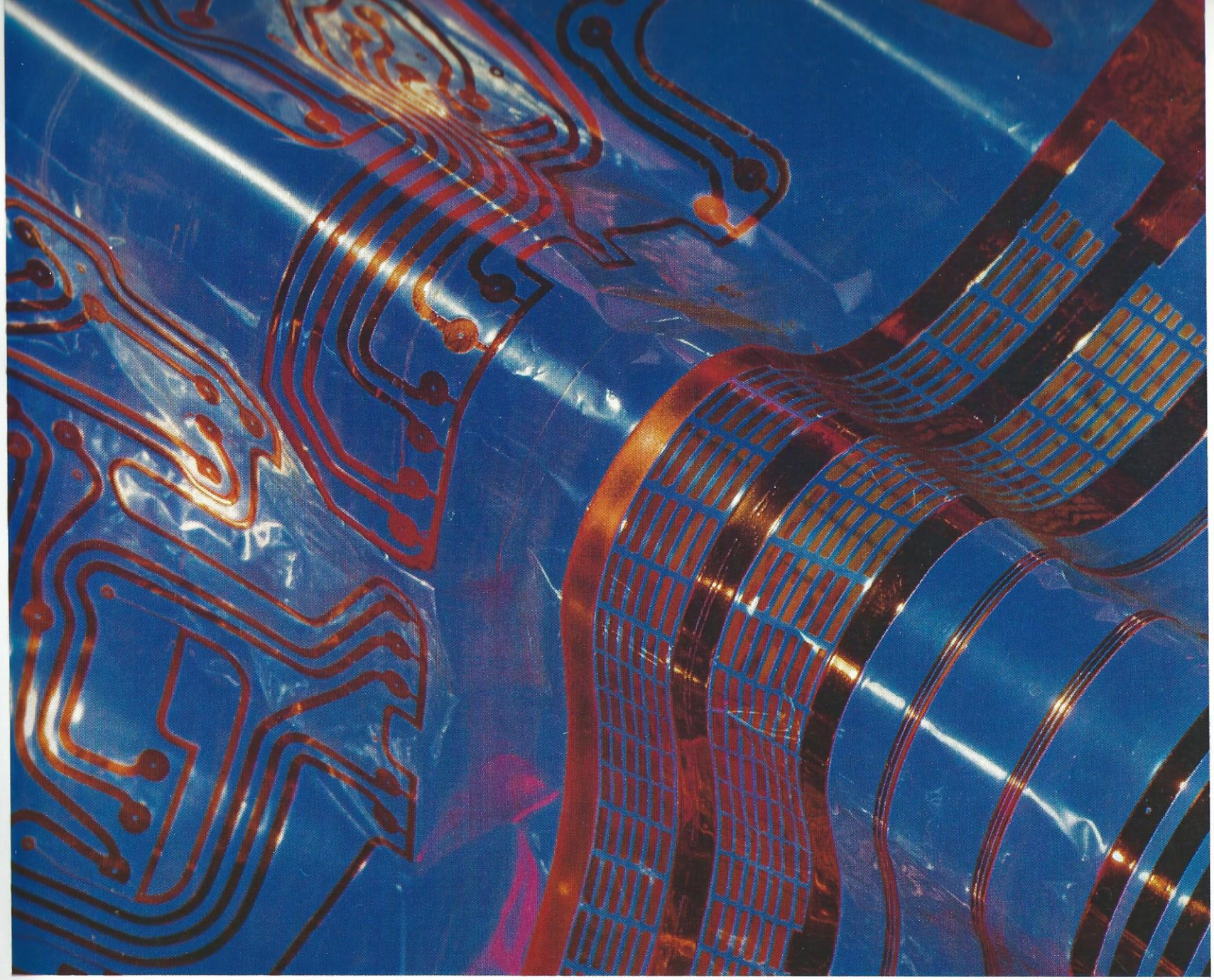
'Because of this, I have been enabled, since my early years, to see that the work of a great man stands first in his life. And that is a good thing. A man does not work for himself alone, but for his family, and, in a wider sense, for the whole circle to which he belongs. And the greater the man's capabilities, the greater the prosperity that will flourish around him, though bringing in its train ever greater responsibility. A responsibility that is a tonic in days of prosperity, but a heavy load in days of adversity.'

*1*
*Enlargement to the original size of a micro-copy, on ultra-violet sensitive PD-film, of page 204 of Anton Philips of Eindhoven by P.J.Bouman (400 diameter reduction). The size of the micro-copy was 0,26 x 0,41 mm², the height of letter e was 4 $\mu$m. The micro-copy, seen under a microscope, reveals the quality much better than the photomechanical reproduction.*

– P.D. type systems – that have varying resolving powers (200 to 2000 cycles/mm) and varying sensitivities, i.e. 10 to 100 times the sensitivity of diazo-type materials. Basically, for all of them the image is built up in three phases: exposure, introduction of the latent metallic image, and intensification of this image. A large variety of materials can serve as a base, from paper to plastics and from wood to aluminium. Preferably, light-sensitive diazosulphonates should be used, but it is possible to choose from several categories of light-sensitive compounds. The development of a special P.D. material for ultramicrophotography (photomasks) is now in a final stage.
Another application of the P.D. systems in electronics is 'P.D. photoplating'. In this process the photographic images are directly developed into electrically conducting external images. These can subsequently be further intensified by electrodeposition. This unique method permits the formation of fine, conducting metal patterns on practically every kind of substrate by an additive method. There is, therefore, no loss of material as in the subtractive method of photo-etching, and no resist layers are required. Through plating of holes presents no difficulties. Mostly a thin layer of synthetic adhesive is applied between the base and the light-sensitive layer. The degree of adhesion is controllable between strong and lasting, and weak and provisional. In the latter case the pattern can easily be stripped from the base. The method is being applied to the production of printed wirings, cable trees, fine screens, coils, etc.
Besides as a photographic tool in electronics, the P.D. process has other possible applications, such as for the storage of information, for the reproduction of aerial photographs and for reprographic processes.



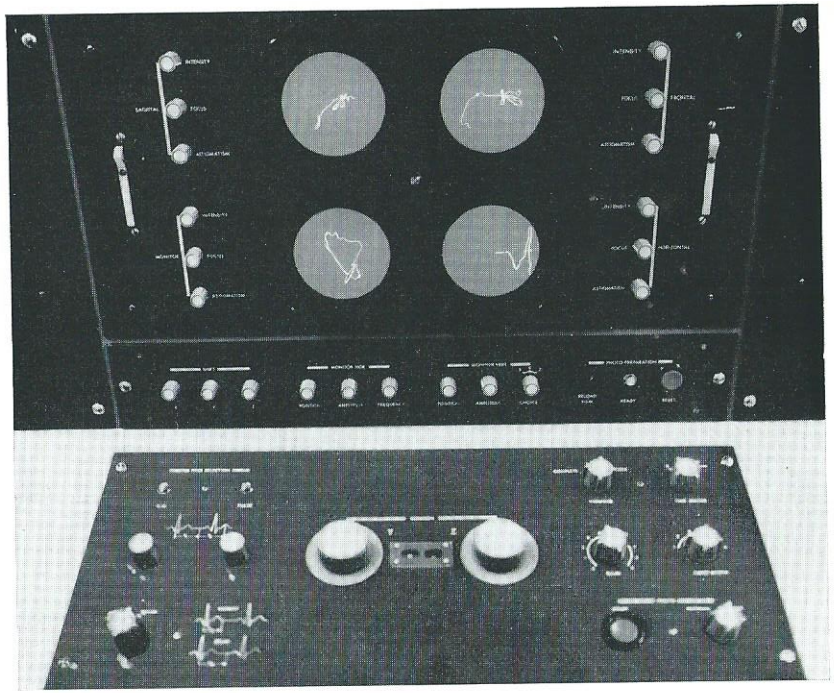
*2*
*Close-up of PD-imaging machine in use at the Radio Factory of Philips.*



*3*
*An abstract looking photograph of conductive patterns on flexible film material made by means of the PD-machine of fig. 2.*

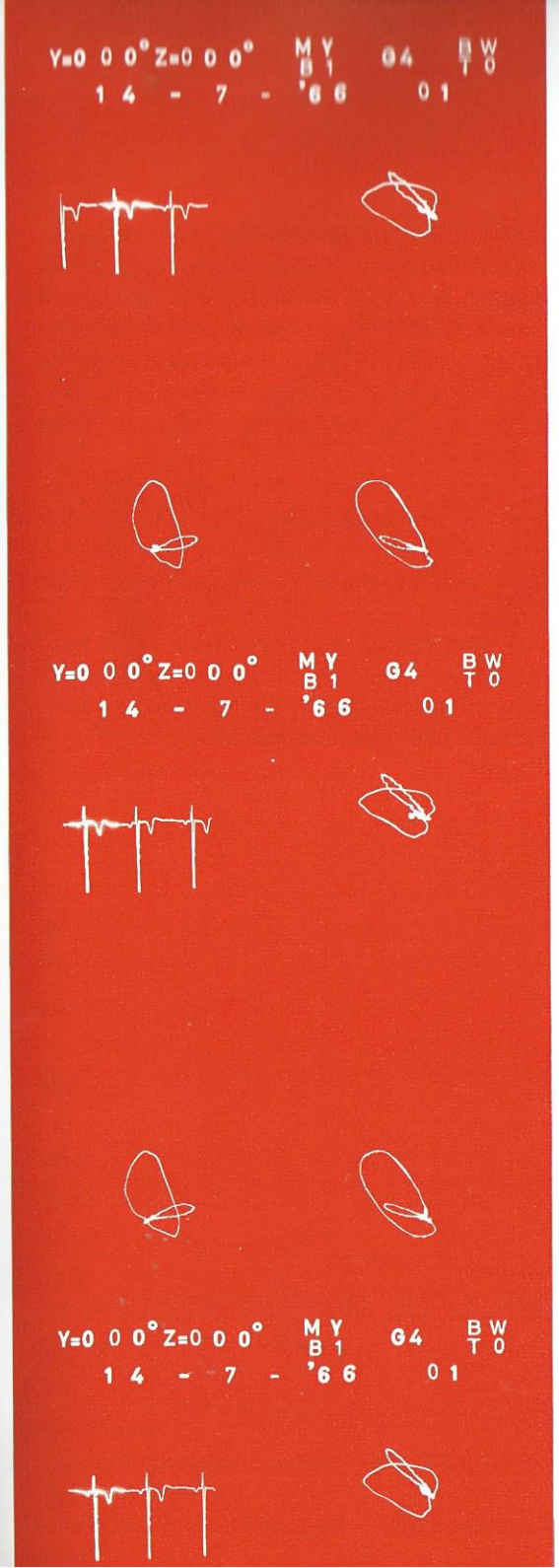
# Instrumentation electronics

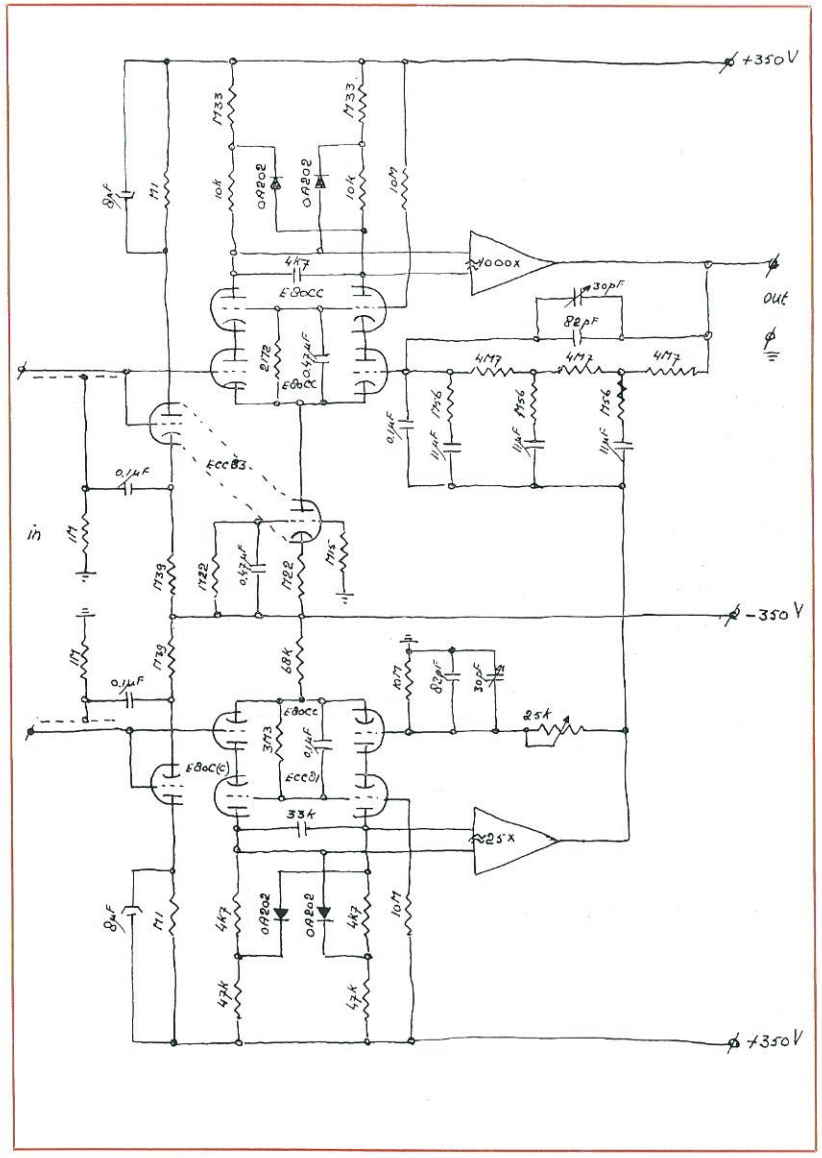
If one tries to develop precision electronic instruments, one soon realizes that the main stumbling blocks are the inaccuracy and instability of the components. In this respect the active elements are the worst sinners: not only do they show the same normal manufacturing tolerances as resistors and capacitors, but their properties are also strongly dependent on supply voltages and on aging. The challenge offered by this situation led to the growth of a branch of electronics that we shall call instrumentation electronics. It is devoted to the development of electronic circuits that perform their function with high precision, notwithstanding the large tolerances in their components.
A programme of this kind looks like trying to find a chain that is stronger than its weakest link. However, it must be realized that the strength of a chain is determined by the weakest link only if all links are in series. As soon as links are put in parallel, the chain may be as strong as the strongest link, or even stronger. Instrumentation electronics makes use of just such seemingly trivial observations, of which some examples will be given, and its success stems from their correct application.
By using feedback, one can make the gain of an amplifier to depend only on the ratio of two resistors. If two resistors of the same type are chosen and if they are placed in the same environment (especially as to temperature), the amplification will show a closer tolerance than either of the resistors, and far closer than that of the amplifying element.
The observation that in a reasonably stable oscillator the loop gain is essentially one can be made use of in the design of a circuit, the gain of which is higher than one and which depends on resistance and capacitance values, but which remains within much closer tolerances than any of the components.
In a triode the cathode and anode currents are equal to a very high degree of approximation and this can be used to advantage in balancing circuits.
Even the very trivial fact that the quantities of electricity that flow into and out of a capacitor in charging and subsequent discharging are identical, can be exploited, for instance in a precision voltage-to-frequency converter.



These simple truths, and a thorough knowledge of the properties of components, can be applied to the design of many types of circuit, such as amplifiers, generators for sine waves, triangular waves or square waves, and to what we usually call 'circuits for analogue mathematical operations', used for addition and subtraction, division and multiplication, and for logarithmic and exponential operations.
An example of an instrument to which a number of these techniques were applied is the vector cardiograph. The example was not chosen for its modern type of circuitry, since many tubes are still employed, but for its complexity. As in many medical applications, one encounters the problem of interfering signals that appear at the same high level on both the electrodes between which the desired signal is present: ratios of $10^2$:1 or even $10^4$:1 may occur. This calls for difference amplifiers with a very high rejection of the common mode ($10^4$ has been realized in this case). Further manipulation of the signals requires summation of signals, rotation of coordinate axes and other transformations as well as programming.
The experience gained in the instrumentation field now turns out to be of unexpected value in the design of integrated circuits. In integrated circuits the manufacturing tolerances of the 'components' are rather large; on the other hand, a great number of components can be made in one operation. Therefore, there is room for applying the methods described in order to arrive at a guaranteed performance in spite of using low-accuracy components.

*1a*
*Vector cardiograph. The four small cathode ray tubes present the three*




2

*Input stage of the vector cardiograph. The differential amplifier has not only a high common mode rejection, but also a very well defined amplification of the common signal. All amplifiers are d.c. coupled, but the frequency characteristic is equal to that of an indirect coupling with a high time constant. In this way it was possible to avoid the long blocking*

# Full-band matching of waveguide discontinuities

Waveguide components such as corners, bends, twists, stepped transformers, isolators, detectors, mode transducers, etc., represent discontinuities that cause reflections. Past attempts to compensate for these reflections have not attained perfect, or near-perfect compensation over the full waveguide band. We have developed a general matching technique permitting the reflection coefficient to be reduced to less than 1% over the whole waveguide band. The principles of the technique are simple, but mathematical treatment is difficult, and our solutions have therefore been obtained by experimental means.

In principle, the reflection caused by a discontinuity is compensated for by means of a discontinuity of opposite sign, but having the same frequency characteristic: $|R|(\upsilon)$. The matching discontinuity, which we shall henceforth call the matching element, must be of the proper nature and fitted at the proper place. This location, called reference plane, coincides with the plane where there is maximum variation of the electric or magnetic field. Therefore, we have classified the discontinuities as symmetrical or asymmetrical, depending on whether the phase-versus-frequency characteristic of the reflection is the same on either side of the discontinuity or not. For symmetrical discontinuities the reference plane coincides with the plane of symmetry. For asymmetrical discontinuities good information can be obtained from the electrostatic or magnetostatic equivalence.

Basic matching elements, such as shunt or series capacitances and inductances were made in the form of variable diaphragms of different thicknesses. In general, a capacitive discontinuity of the shunt type can either be compensated for by another, having opposite sign, or by a series inductance, or inversely.

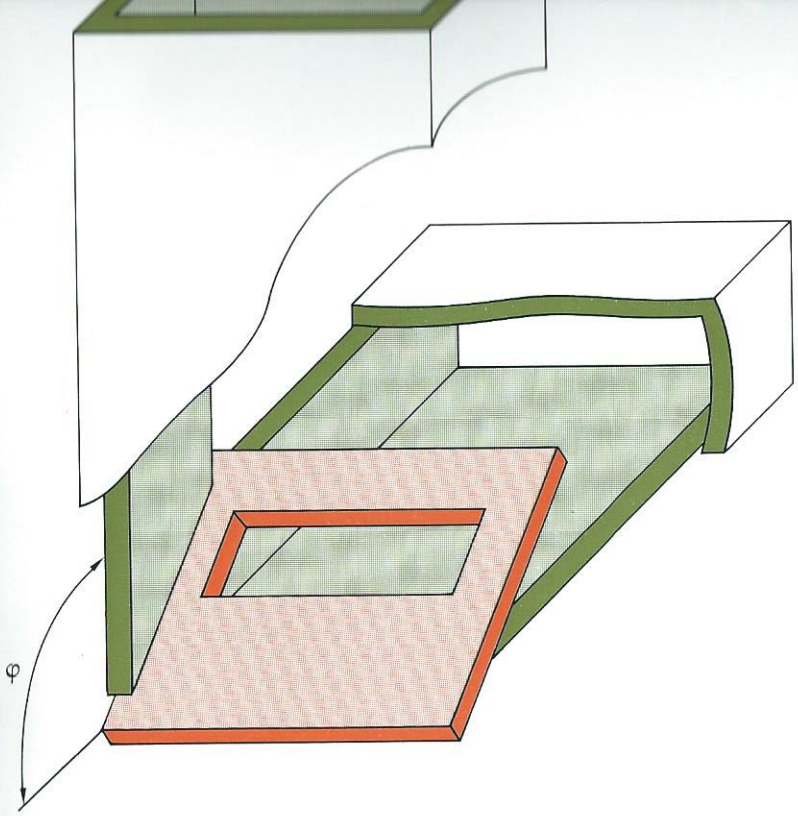
We shall describe one example of the matching of a symmetrical discontinuity, and one of an asymmetrical discontinuity, viz. a corner and a step, respectively.

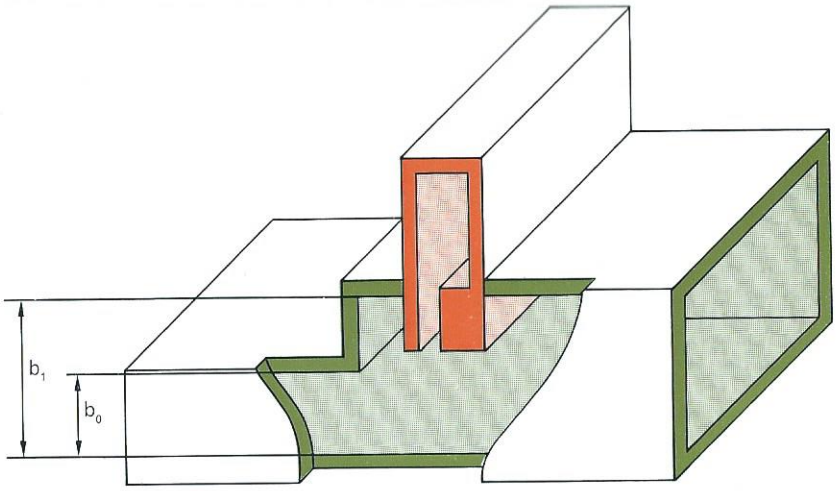
For an E-plane corner *(see fig.1)*, the electric field in the plane of symmetry must be exactly transverse. Without matching, higher modes occur, resulting in large reflections. From the electrostatic equivalence it becomes evident that these can be eliminated with the aid of an excentric capacitive diaphragm. Based on the magnetostatic equivalence, a similar reasoning can be given for the H-plane corner.

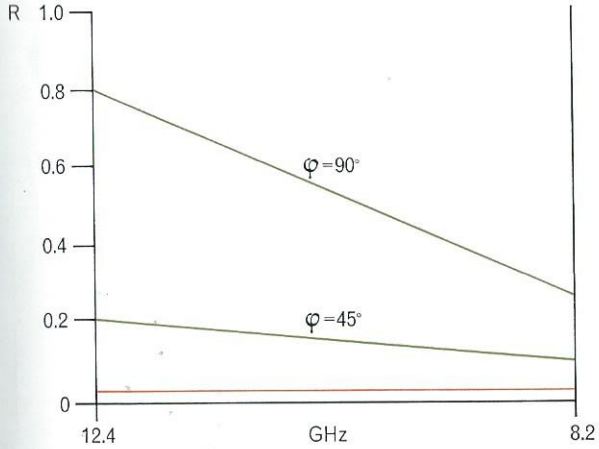
Sudden changes in height or width, i.e. for E or H-plane steps, are equivalent to a shunt capacitance or shunt inductance, respectively. From the frequency curve this is evident for the H-plane step, but not for the E-plane step. Therefore, the H-plane step is easy to match by means of a series capacitance at the position of maximum magnetic field variation. In order to obtain the proper frequency curve for the matching element of the E-plane step, a combination of a shunt and a series capacitance is required *(see fig.2)*.

Our matching technique is also applicable to more complicated structures such as tees and transitions from one type of transmission line to another, even a transition from an empty waveguide to one partially or completely filled with a dielectric or magnetic material with or without losses.

All experimental work has been carried out for the X-band, but the technique can also be applied to other frequency bands and other types of transmission line. Complete matching over a full octave can be obtained for discontinuities in TEM transmission lines.



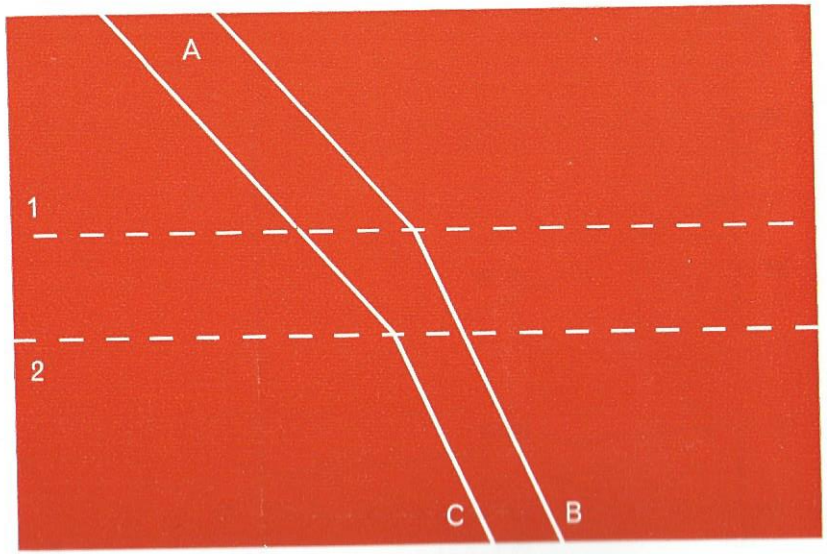

*1*
*E-plane corner.*
*a. The matching excentric diaphragm, being almost capacitive (dependent on φ), is given in red.*
*b. The reflection coefficient |R| versus frequency for unmatched and matched corners.*


*2*
*E-plane step.*
*a. The matching element, a combination of shunt- and series capacitance in order to obtain the right frequency characteristic, is given in red.*
*b. The reflection coefficient |R| versus frequency for unmatched and matched steps.*

# Digital displacement measurement with the aid of an optical grating

Digital measurement and display of the co-ordinates of machine tools, convenient in itself, is indispensable if the machine is to be controlled numerically. It is also important for measuring machines and permits automatic printing of the results.
Maximum precision in measuring the movement of the carriage of a machine tool along its bed is attained if a linear transducer is used that transforms the displacements directly into electrical signals. Such a transducer has two parts; some form of measuring scale fitted to the carriage, and a reading head fixed to the bed.
At present machine tools attain accuracies of 1 micron or better. For digital read-out of this precision there are two alternatives: either to use a finely divided scale giving the small steps directly, or to use a scale with larger intervals of, say, 0,1 mm or more and to obtain the fine steps by interpolation. We have chosen the first alternative, as interpolation always introduces the possibility of periodic errors. The scale we use is an optical grating, with a period of 8 microns, for instance. By optical and electronic means we obtain an inherent 16-fold subdivision of this distance, so that the true digital steps are 0,5 μm. The same reading head can also be used with scales of larger period if such fine steps are not needed.
If, according to a principle described by Guild some ten years ago, a beam A *(see fig.1)* is projected on to two closely spaced gratings 1 and 2, two parallel beams B and C (the other diffracted beams are not used) can be collected, of which the former has been diffracted at grating 1 only and the latter at grating 2 only. When the gratings move in relation to one another, the relative phase of the two interfering coherent beams B and C varies and the combined beam (B + C) will fluctuate in intensity. This can be detected photodetector.
The simple arrangement of fig.1 is not suited to our purpose. We have therefore designed a novel system employing only one reflecting diffraction grating that is scanned by an optical imaging system *(fig.2)*. The mirror and the specially designed lens project an inverted image of the grating onto itself. The imaging system fulfils the same function as the reference grating of fig.1 We thus avoid the use of two closely spaced gratings. All optical components are on one side of the grating, which can now be clamped directly to the carriage.

The grating is of the 'phase' type, which gives 16 times as much light as an 'amplitude' grating. By causing the mirror to vibrate (dotted lines) we obtain an a.c. signal, even at standstill of the grating, which allows the use of less critical circuitry. A birefringent quartz plate, together with a polarizing beam-splitting prism enable us to determine the direction of motion from the sign of the 90° phase difference between the two photocell signals. The use of symmetrical orders of diffraction gives the combined advantages of halving the digital steps and allowing the use of white light.
Small scratches or specks of dirt on the grating do not deteriorate the system, which observes about 1 cm² of the grating. Lining up the grating is greatly facilitated by the fact that the plane of the grating may be up to 0.1 mm out of focus either way without the signals disappearing. The maximum permissible carriage velocity is limited only by the maximum light modulation frequency that can be detected by the photocells and subsequently amplified, and exceeds 20 cm/s (12 m/min). This is sufficient for all applications so far envisaged.




*1*
*Diffraction by a grating. Beam B has been diffracted at grating 1 only,*

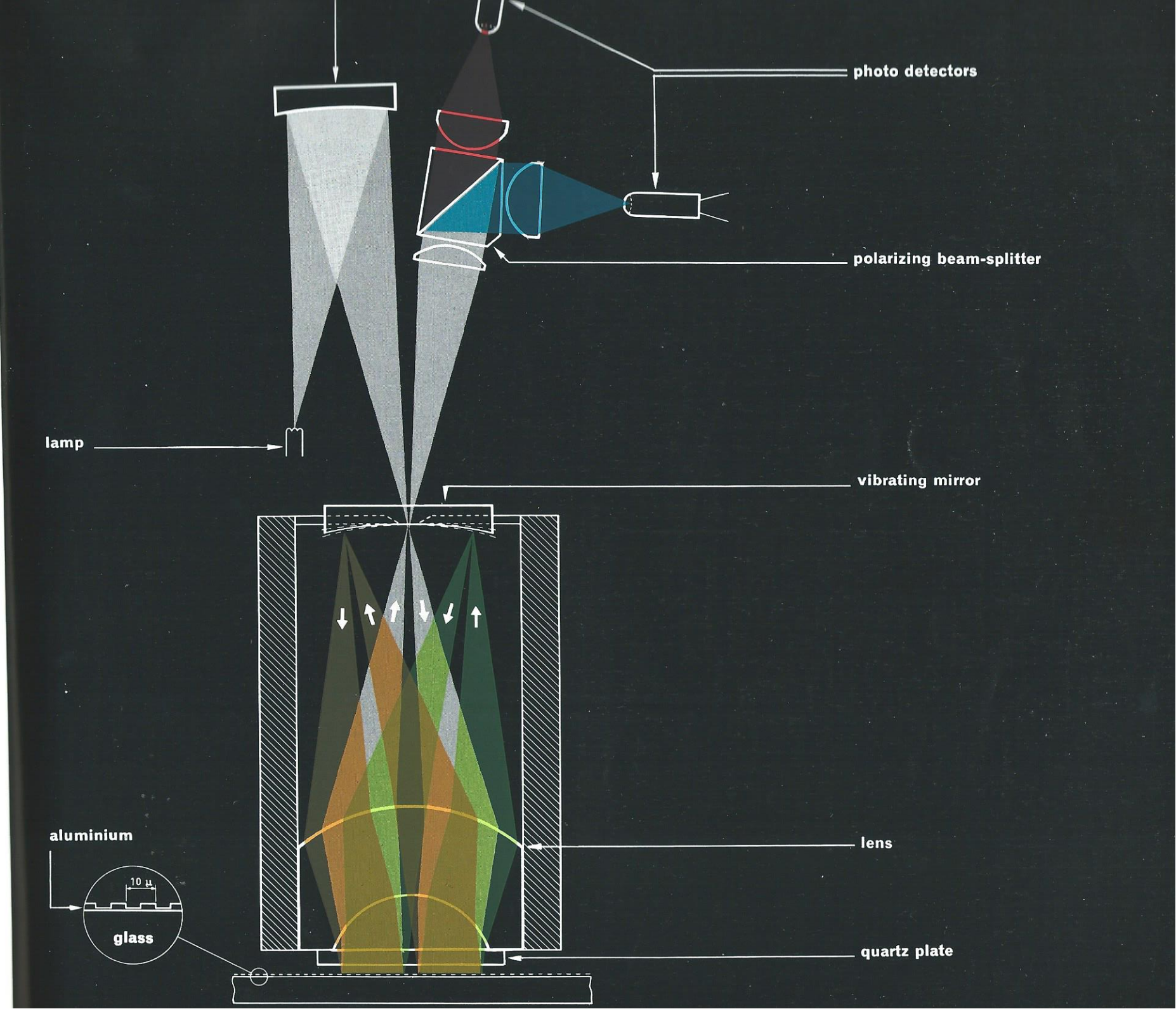


photo detectors
polarizing beam-splitter
lamp
vibrating mirror
aluminium
10 μ
glass
lens
quartz plate

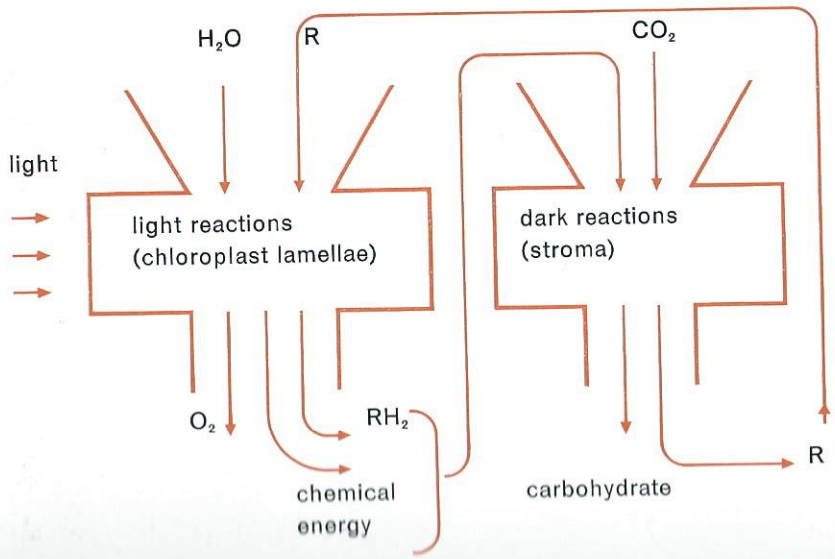
By utilizing the energy of light, plants are able to transform carbon dioxide and water into organic compounds, especially carbohydrates. This process, called photosynthesis, may in principle be represented by the following reaction scheme:

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\ O_2.$$

The transformation of carbon dioxide and water into organic compounds consists of two separate processes:

1. Light reactions. Light is absorbed and transformed into chemical energy, with the result that water is split, while both a reducing and an energy-rich compound are formed.
2. Dark reactions. With the aid of the energy-rich compound, the reducing compound reduces carbon dioxide to carbohydrate.

Both processes proceed via a considerable number of intermediate steps. The overall process of photosynthesis is visualized in the following diagram, in which the reducing compound is represented by $RH_2$:

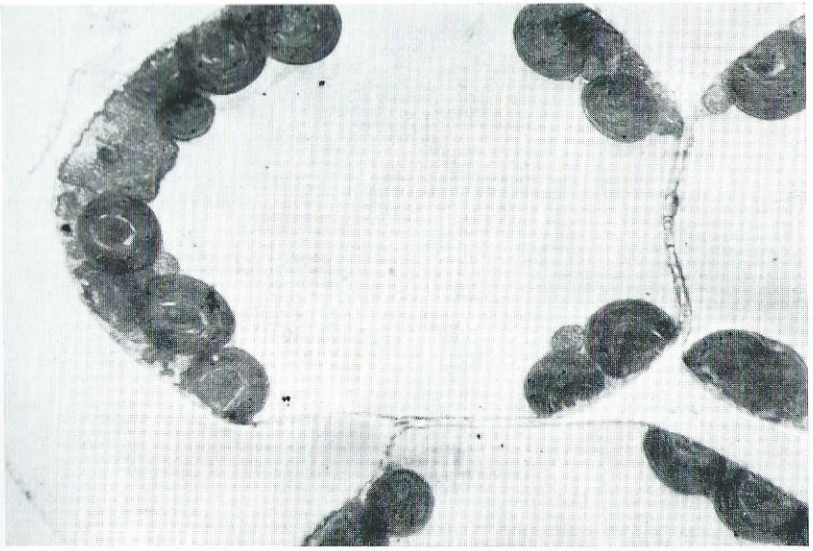



Plant photosynthesis is localized completely in so-called chloroplasts, which are a special kind of cell organelles. Normally, they are to be found at the sides of the cell wall *(fig.1)*. Chloroplasts are small discs or flat ellipsoids of about 5 microns diameter. They contain chlorophyll and other pigments that are necessary for the absorption of light and its transformation into chemical energy. In the chloroplasts one finds lamellae *(fig.2)*, that can be separated from the rest of the chloroplast, called stroma. The light reactions of photosynthesis occur in these chloroplast lamellae; the reduction of carbon dioxide to carbohydrate occurs in the stroma.

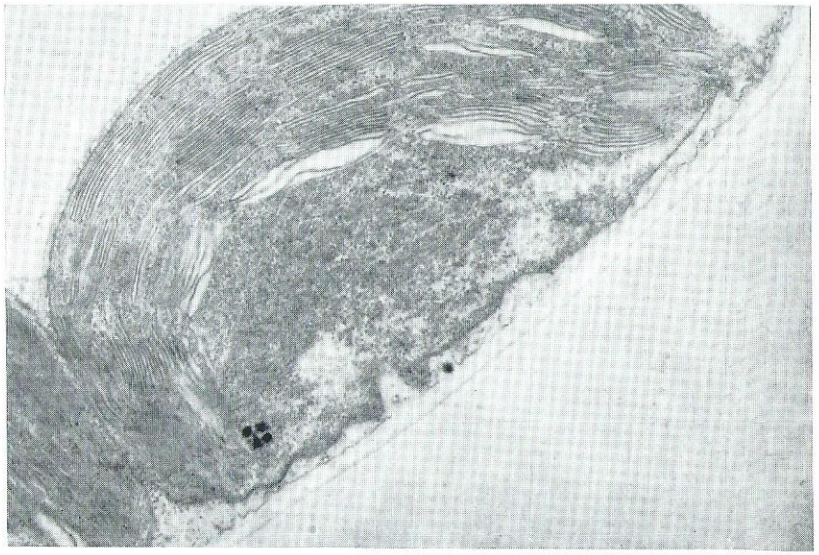
By combining biochemical research and electron-microscopical observation, it is possible to get an insight into the exact localization of the different intermediate steps of photosynthesis. Such an insight may assist in the study of specific inhibitors of photosynthesis. The latter may be used as herbicides and have the advantage of being non-toxic for man and animals.

The series of four accompanying photographs have been taken by means of the electron microscope. Fig.1 shows a number of chloroplasts, while fig.2, at greater magnification, shows the lamellae and the stroma. In fig.3, where the magnification is 27,000 times, the chloroplasts have been treated with a detergent. The stroma has disappeared and the dark reactions have ceased; light reactions still take place. It will be seen that the chloroplast lamellae have got localized constrictions. When the concentration of the detergent is increased, the chloroplast lamellae are broken up into smaller vesicles having a diameter of 50 to 200 μm. At intermediate concentrations of the detergent these vesicles appear to be stacked with small particles (8 μm or 80 Å), as seen in fig.4. These particles, which disappear at high detergent concentrations, appear to be connected with the formation of the energy-rich compound, since this process stops the moment these particles disappear.

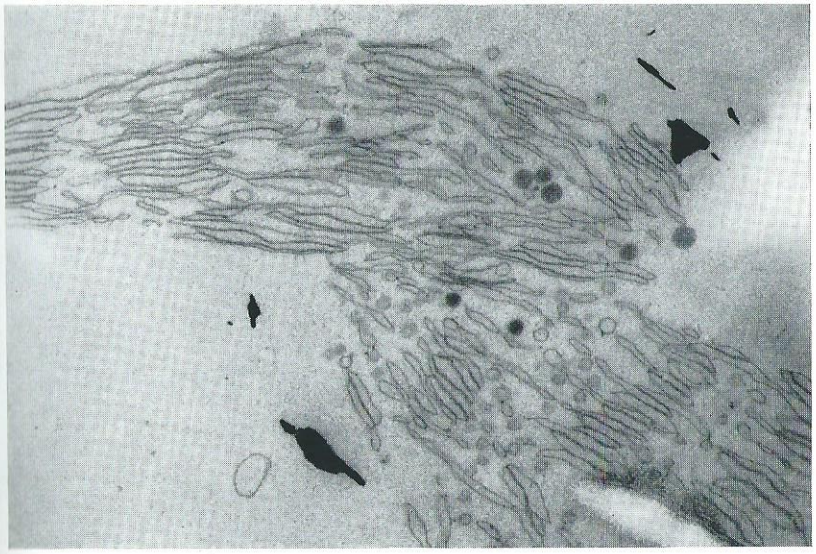
1



2



3



4

# The Philips Stirling Gas Refrigeration Machine

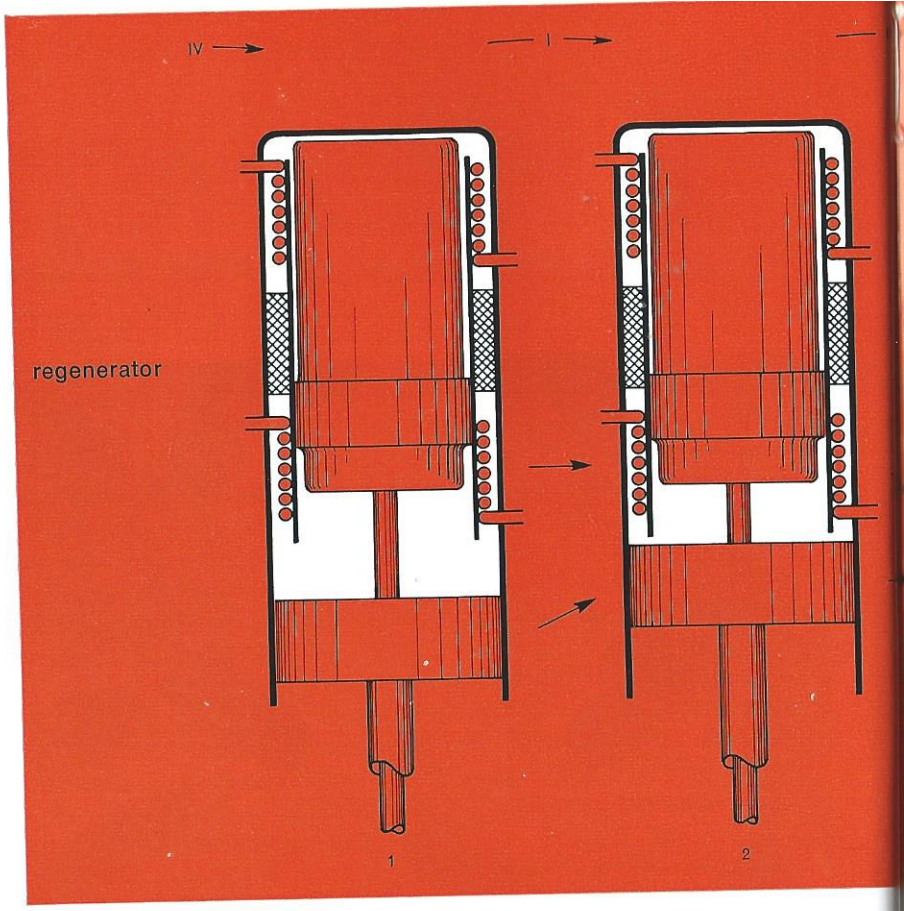
Stirling invented the hot gas engine 150 years ago; in 1832 it was found that its underlying principle could also be used for refrigeration. Both processes have remained rather dormant until 1938. Then their scientific analysis was taken up again in the Nat.Lab. Among other things, this work has produced the present Philips Stirling refrigeration machines which are suitable in particular for refrigeration at very low temperatures (below 100° K).

The fairly simple diagram of fig.1 is representative of the process which, upon closer analysis, will be found to be rather complicated, mainly because all subsidiary processes such as compression, expansion, regeneration and heat transfer, take place in one and the same closed space. In the following we shall, with the aid of a few examples, explain that this creates problems which only a very thorough scientific approach can solve.

Ideally, the cold produced is defined by $\oint p\, dV$ over the cold space. For a good design accurate prediction of the pressure variations within the machine is therefore necessary. These variations are influenced by a number of factors, first of all of course by the volume variations. The gas temperatures in the various sections of the machine also have an important bearing on the problem, as have the flow resistances, and in addition the temperature and pressure variations are interdependent.

Besides the pressure variations, the transfer of heat has an important influence on the temperature variations of the gas. In a machine operating between room temperature and 100° K and running at 1500 r.p.m., the gas in the regenerator must be cooled 200° C in .02 seconds, which means that the cooling rate is appr. 10,000°/sec.

It will be obvious that such a requirement calls for a thorough investigation into the problem of heat transfer, especially because the temperature variations not only have a bearing on the pressure variations, but determine the regeneration losses directly. How important these losses are can be seen from the pV diagram of fig.2, in which the process has been formalized to 2 isotherms and 2 isobars. $Q_2$, the quantity of heat to be stored in the regenerator, is equal to $Q_1$, the quantity to be released to the gas, but it is 15 times as large as the ideal cold production $Q_E$ *(see caption to fig.2)*. If only 1% of $Q_2$,

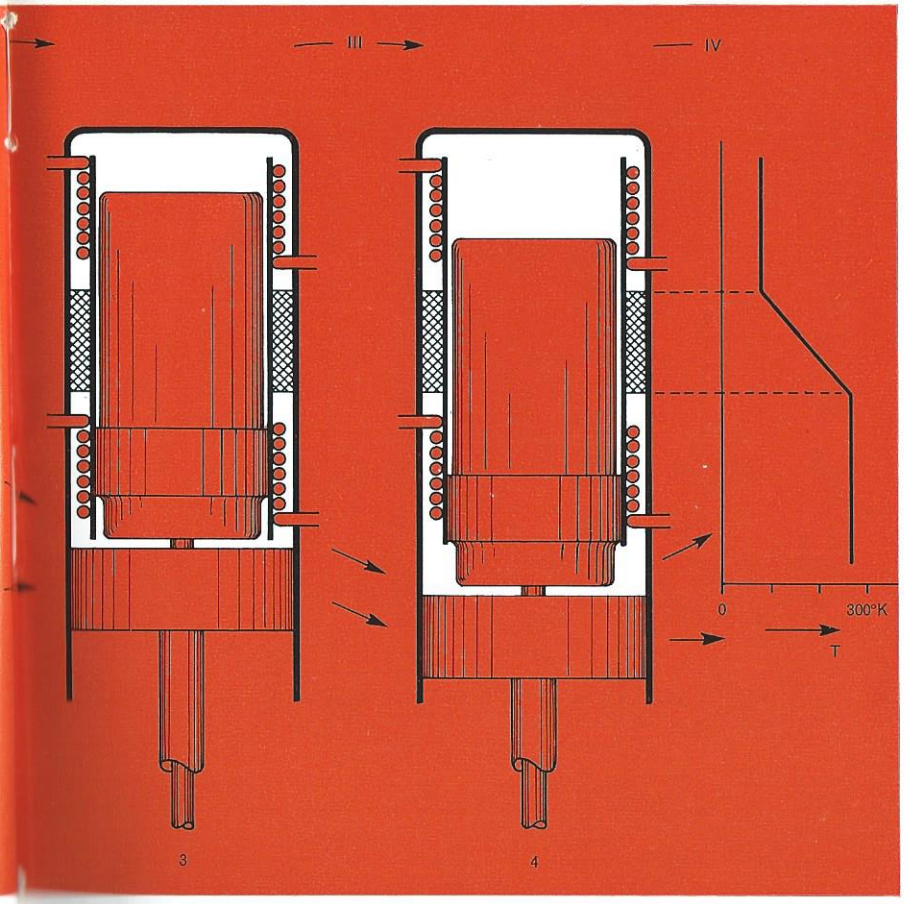


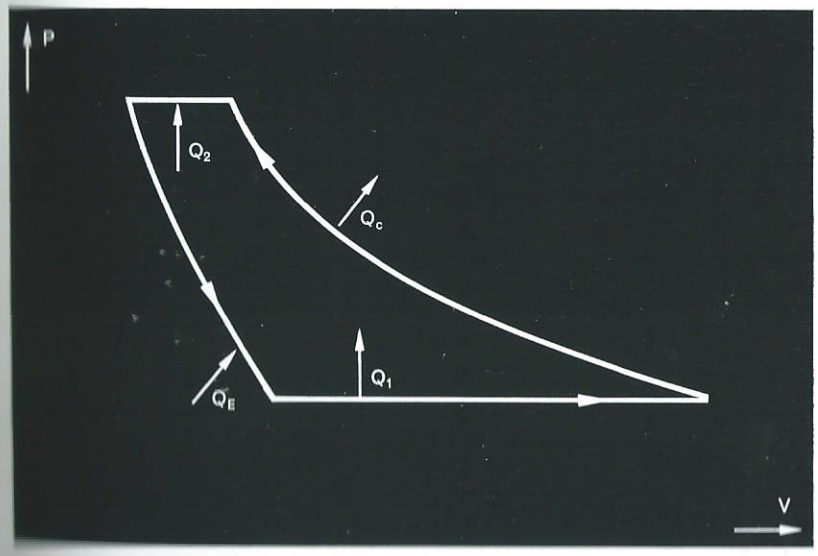

instead of being absorbed by the regenerator, gets into the expansion space, 15% of the ideal cold production is already lost.

Besides the heat transfer, the heat capacities of the materials play an important part in the regenerator. Since these heat capacities diminish very rapidly at low temperatures (Debije's law), regenerators cannot possibly be built in such a way that the temperature variations of the materials remain small. These variations will then also influence the temperature variations of the gas and, with it, the pressure variations and the regeneration loss. Even the gas flow can be changed considerably by them.

These are only a few of the problems of the Stirling machine. It is clear, therefore, that extensive investigation and teamwork of a theoretical and experimental nature, covering thermodynamics, materials technology and design have been necessary to bring the Stirling process to bear fruit. This fruit is the range of Philips Stirling refrigeration machines covering a temperature range from 12°K to 150°K and producing from 1 to 20,000 Watts of cold.

*1*
*Phase I Compression of the gas at room temperature*


III
IV
0
300°K
T
3
4


P
$Q_2$
$Q_c$
$Q_E$
$Q_1$
V