A universal vectorcardiograph

In conventional electrocardiography the potential difference which appears between two points on the surface of the human body during the heartbeat is recorded as a function of time. A number of such electrocardiograms recorded for various pairs of points, which are referred to as "leads", provide the cardiologist with information about abnormalities in the action of the heart.

The discovery that the phase difference between the time functions obtained from different leads is also of importance led to the development of vectorcardiography [1]. If the potential differences from *two* leads are plotted one against the other, the result is a kind of Lissajous figure. If the time scale is marked on this figure, we then have another way of displaying information about the action of the heart. To a first approximation the Lissajous figures can be regarded as representing, for all possible pairs of points, projections of one and the same curve described in space and characterizing the heart under examination. The radius vector of this three-dimensional curve is called the instantaneous heart vector; the curve displays the variation of the heart vector during the heartbeat, hence the term "vectorcardiogram".

The vectorcardiogram has proved to be a valuable aid in diagnosis, as it is closely correlated with the action of the human heart, and will show if any abnormal condition is present. Individual loops in the vectorcardiogram correspond to the different phases in the heartbeat, each of which gives a peak in a conventional electrocardiogram; see *fig. 1*. The non-specialized physician can learn to interpret the vectorcardiogram more easily than a conventional electrocardiogram. The vectorcardiogram has specific advantages for the recognition of certain disorders, whereas the conventional electrocardiogram remains the best means of investigating rhythmic disturbances. The two methods complement one another.

The Philips Medical Service at Eindhoven is now using an experimental vectorcardiograph, developed at the Philips Research Laboratories, which makes it very easy for the doctor to display and study the vectorcardiogram in a variety of forms (*fig. 2*). A brief description of this equipment now follows. (We should add that it is not commercially available.)

A number of electrodes are applied at appropriate positions to the patient under investigation, and three or more independent leads are taken from the electrodes. Lissajous figures can be produced from these leads in the way described above. In order to interpret these figures, it is desirable, however, that they should be reduced to projections of the three-dimensional curve described by the heart vector on the three planes of a rectangular co-ordinate system (X, Y, Z). This is done by means of a linear transformation, i.e. appropriate fractions of the potential differences from all the leads are added together in a mixing circuit so as to obtain signals which are proportional to the components X, Y and Z of the heart vector. The correct fractions of each of the original signals for a selected lead system are determined empirically, and provide the data for adjusting the values of the resistors in the mixing circuit into which the signals are fed after amplification. The pairs of component XY, XZ and YZ are then applied to the deflection plates of three cathode-ray tubes, one tube for each pair, each tube thus indicating one of the required projections of the vectorcardiogram.

There are at present various internationally standardized lead systems in use. The number of leads depends on the system employed. Our vectorcardiograph is designed to be used with up to six leads. With this arrangement the cardiologist is able to choose between two standard lead systems incorporated in the instrument (the Frank system and the Burger-Wilson system) and a third which he can decide upon for himself. If all the electrodes have been applied previously

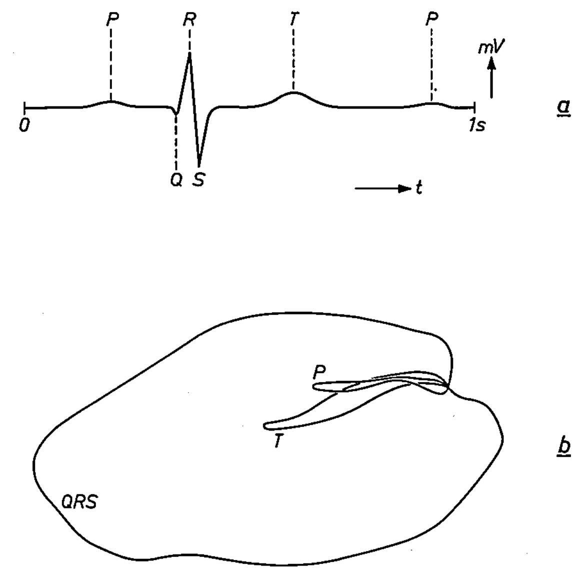


Fig. 1. *a*) Conventional electrocardiogram. *b*) Perspective sketch of a vectorcardiogram. The peaks in the conventional electrocardiogram are indicated in the same way as the corresponding loops in the vectorcardiogram.

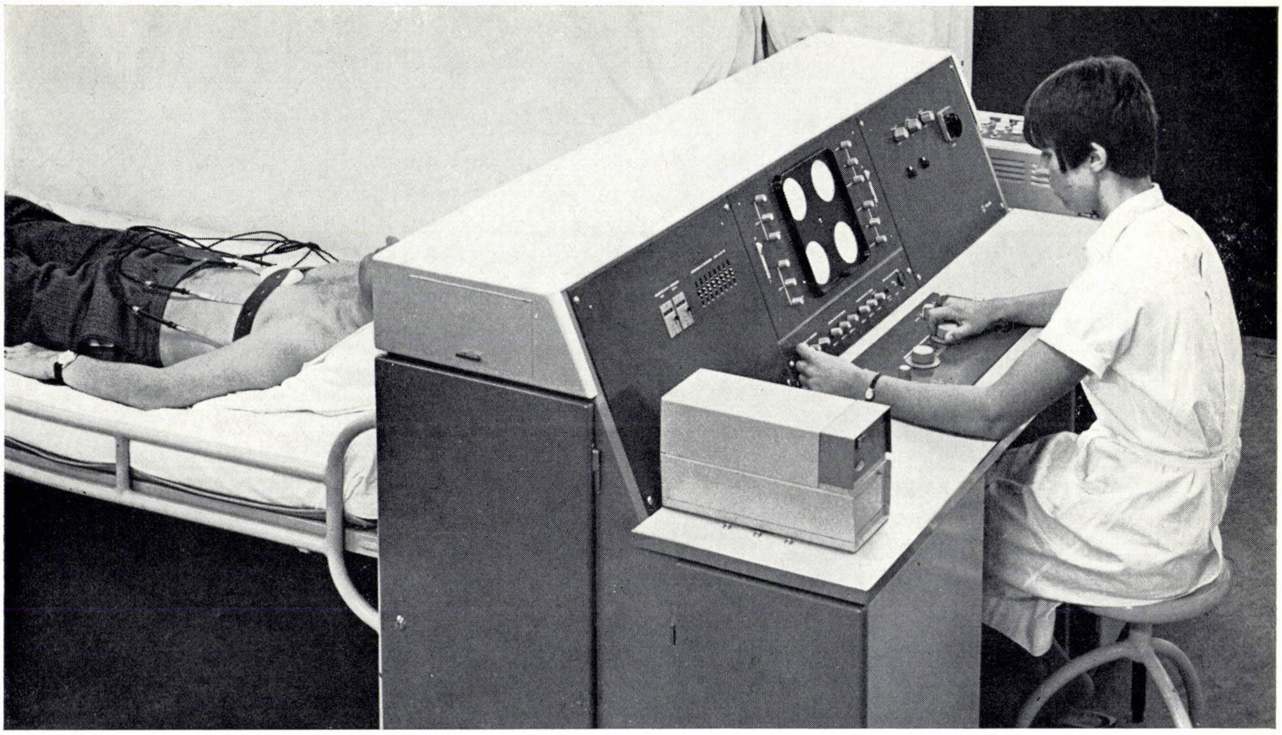


Fig. 2. The experimental vectorcardiograph, developed at Philips Research Laboratories and in use at the Philips Medical Service at Eindhoven.

he can switch over from one system to the other. This offers the facility of comparing the merits of the different lead systems.

A very useful feature is a circuit device for rotating the system of axes around the Y axis and the Z axis. A loop can thus be viewed from the most suitable angle and a good impression obtained of its spatial orientation.

In addition to the three cathode-ray tubes for displaying the projections of the vectorcardiogram there is a fourth tube, the "monitor". Any one of the three components X, Y or Z can be displayed on the monitor screen as a function of time, the curve thus obtained corresponding to a conventional electrocardiogram (derived however from a composite rather than a bipolar lead). The QRS peak of this electrocardiogram (see fig. 1*a*) is used in the instrument for supplying control pulses to various ancillary circuits.

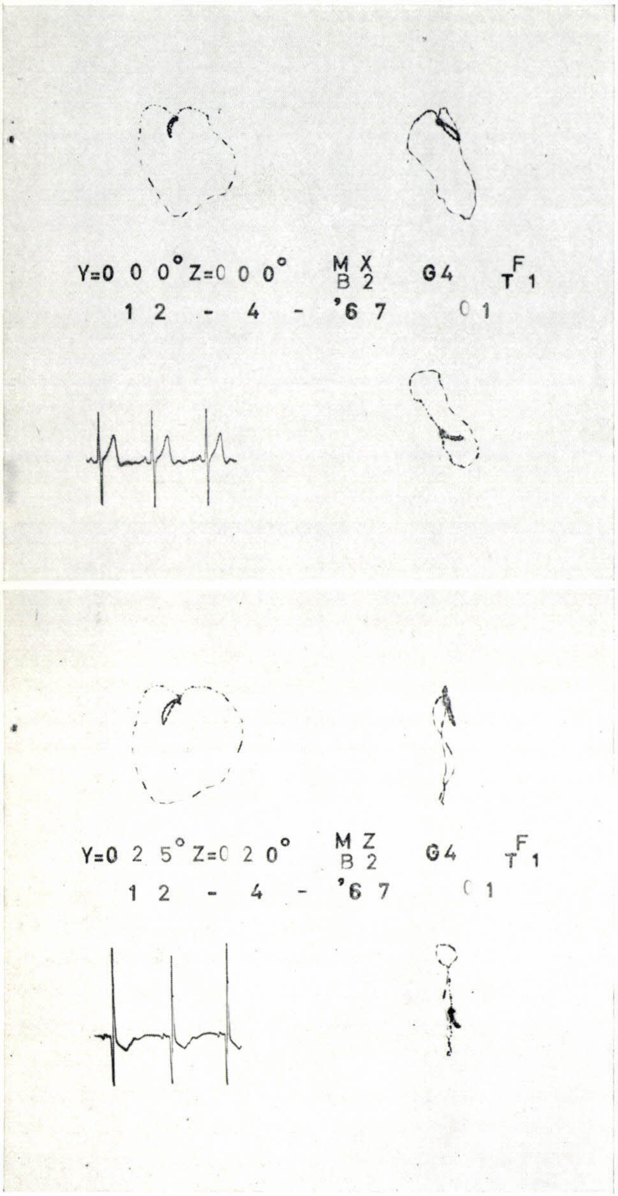
The amplification of the signals can be varied in eight steps of $\sqrt{2}$, and the bandwidth in six steps from 50 Hz to 5000 Hz. There is a built-in oscillator for testing the complete amplifier and mixing circuit. The use of special circuits [2] ensures that when the cable connected to the patient has a length of 6 m the combined level of the hum and noise signals is no greater than about 1 % of the signal from a normal QRS loop of a vectorcardiogram. All the circuits between the patient and the cathode-ray tubes are direct-coupled; this has the great advantage that there are no long blocking times if a circuit should be overloaded.

In the design of the vectorcardiograph considerable attention was given to easily operated devices for displaying either a complete cycle or, for closer study, a selected part of a cycle. The selection of a particular part of the cycle for photographing is done by connecting the signal through only during a particular time interval and suppressing it for the rest of the cycle. The selected portion is indicated on the monitor by extra brightness. Special attention was also paid to arrangements for automatically photographing the screen displays. This is done with the aid of four other cathode-ray tubes (the phototubes), which are connected in parallel with the four display tubes shown in fig. 2; the displays on the phototubes are simultaneously photographed on 70 mm film.

During the writing of the vectorcardiogram the electron beam is periodically suppressed for a few milliseconds to obtain a time marking. Since in addition the beam current and thus the brightness of the picture

[1] G. C. E. Burger and G. Klein, Philips tech. Rev. **21**, 24-37, 1959/60.
For a recent survey, see S. Boutkan, Vectorcardiography, physical bases and clinical practice, Centrex Publishing Co., Eindhoven 1965.

[2] Circuits like those used here are described in: G. Klein and J. J. Zaalberg van Zelst, Precision electronics, Centrex Publishing Co., Eindhoven 1966.



a

b

Fig. 3. Photographs of the displays on the screens of the four cathode-ray tubes. The coding shows that in *a)* the co-ordinate system has not been rotated ($Y = 000°$, $Z = 000°$) and that the X component is displayed on the monitor (MX). In *b)* the co-ordinate system has been rotated 25° about the Y axis and 20° about the Z axis. Here the Z component is displayed on the monitor. Since the whole cycle is displayed, the area around the origin is very dark, obscuring the smallest loop. This drawback can be overcome by displaying only part of the cycle.

is modulated so that a) each point where the trace is interrupted has the form of an arrow, and b) one in every four line sections is given extra brightness, it is possible to determine the direction in which the heart vector curve is described, the total time it takes to describe it, and also the corresponding points in the three projections. Modulation of the electron beam is also used to ensure that variations in the writing speed of the beam as it traces out the picture do not cause excessive brightness differences in the display.

When the camera control button is operated the camera shutter opens. The screens of the phototubes for the three projections, which are normally dark, then display the part selected from the cycle, which is immediately photographed, together with the picture on the photomonitor and data on the rotation of the co-ordinate system, the lead system employed, amplification, date, the patient's serial number, and so on. Typical photographic recordings are to be seen in *fig. 3*. After 4 seconds the shutter again closes and the film is automatically transported. The system contains a variety of precautionary devices, for preventing double exposures, etc.

The instrument is suitable both for fundamental research and for routine examinations. To assist routine work it is fitted with two inputs, which permit change-over from one patient to another without loss of time.

F. Douma
J. Guldemond

F. Douma and J. Guldemond are with Philips Research Laboratories, Eindhoven.