# United States Patent [19]

**Weinfurt et al.**

[11] **3,811,040**

[45] **May 14, 1974**


[54] **VECTOR CONTOUR PLOT OF PHYSIOLOGICAL PARAMETERS**


[75] Inventors: **Phillip T. Weinfurt**, Brookfield; **Robert P. Lijewski**, Milwaukee, both of Wis.

[73] Assignee: **General Electric Company**, Schenectady, N.Y.



[22] Filed: **Sept. 27, 1972**

[21] Appl. No.: **292,605**

[52] **U.S. Cl.** .......... **235/193**, 128/2.06 V, 235/151.3

[51] **Int. Cl.** .......... **A61b 5/04**

[58] **Field of Search** .......... 235/193, 151.3, 151; 444/1; 128/2.06 V, 2.06 R; 340/324 A, 324 AD



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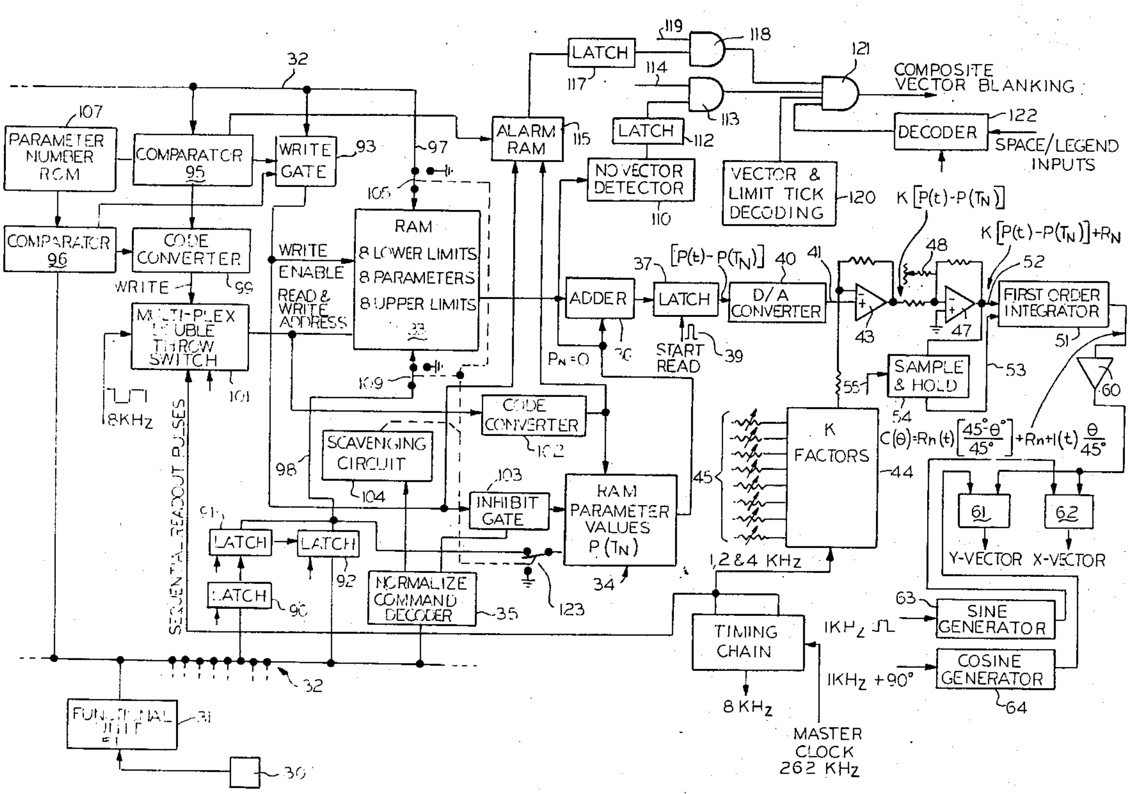
*Primary Examiner*—Joseph F. Ruggiero

*Attorney, Agent, or Firm*—Ralph G. Hohenfeldt; Fred Wiviott


[57] **ABSTRACT**


Equiangularly spaced vectors correspond respectively with physiological parameters such as heart rate, blood pressure and others. The ends of the vectors are connected and preferably form a circular contour on an oscilloscope display screen or printed readout. Variation of the vectors from their reference or normalized value causes the contour to change. Converse operation is also explained. Limit markers for each vector parameter are displayed. An algorithm for representing the parameters as a contoured figure is presented. The plot generator may be built with analog or digital devices or both.


**18 Claims, 17 Drawing Figures**



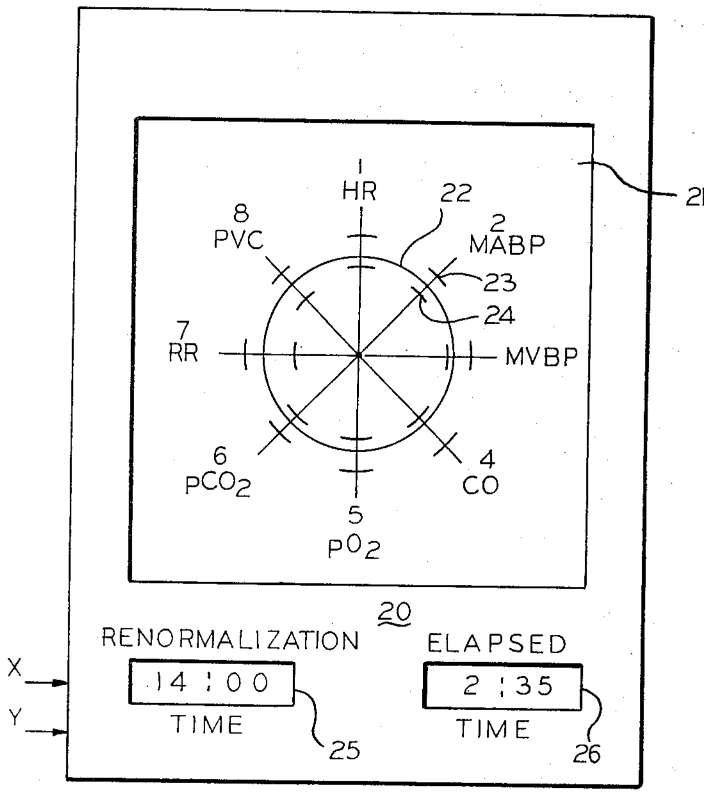



FIG.1

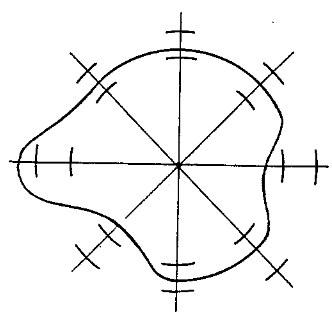


FIG.3

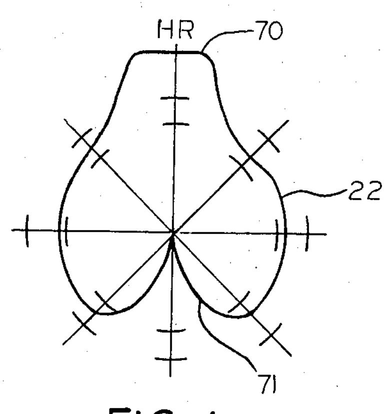



FIG.4

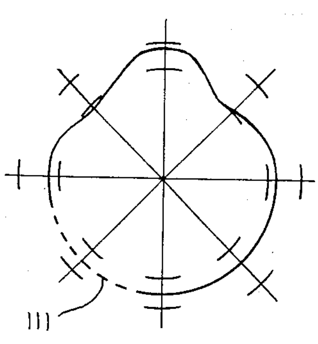



FIG.5

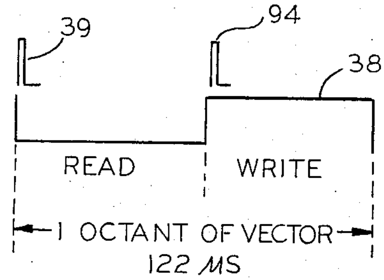



FIG.6

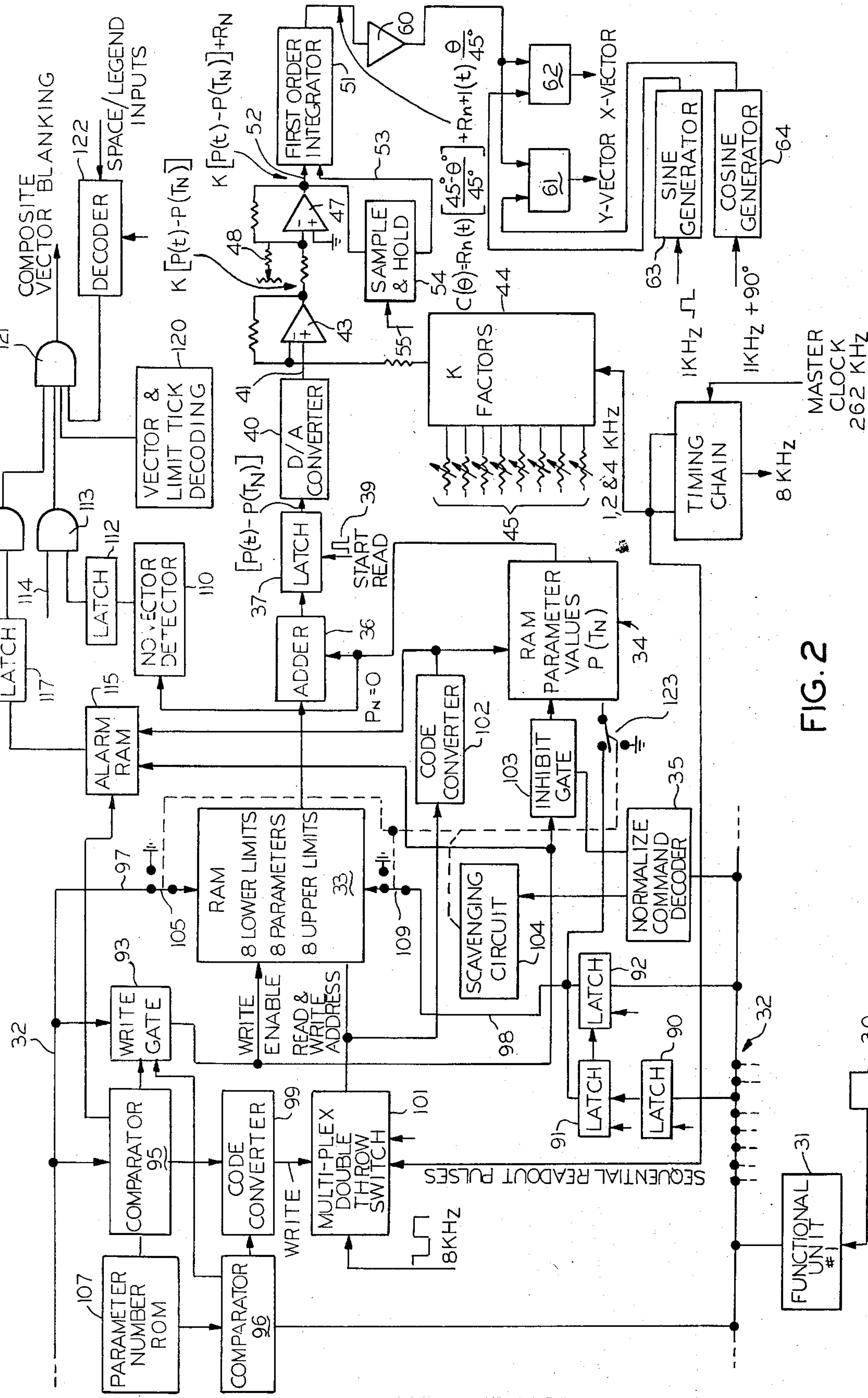

COMPOSITE VECTOR BLANKING
SPACE/LEGEND INPUTS
DECODER
VECTOR & LIMIT TICK DECODING
NO VECTOR DETECTOR
LATCH
ALARM RAM
ADDER
LATCH
D/A CONVERTER
START READ
FIRST ORDER INTEGRATOR
SAMPLE & HOLD
K FACTORS
RAM PARAMETER VALUES P(TN)
CODE CONVERTER
INHIBIT GATE
NORMALIZE COMMAND DECODER
SCAVENGING CIRCUIT
RAM 8 LOWER LIMITS 8 PARAMETERS 8 UPPER LIMITS
WRITE ENABLE
READ & WRITE ADDRESS
WRITE GATE
COMPARATOR
PARAMETER NUMBER ROM
MULTI-PLEX DOUBLE THROW SWITCH
SEQUENTIAL READOUT PULSES
SINE GENERATOR
COSINE GENERATOR
Y-VECTOR
X-VECTOR
TIMING CHAIN
MASTER CLOCK 262 KHz
8 KHz
1,2 & 4 KHz
1KHz
1KHz +90°
FUNCTIONAL UNIT #1

FIG. 2

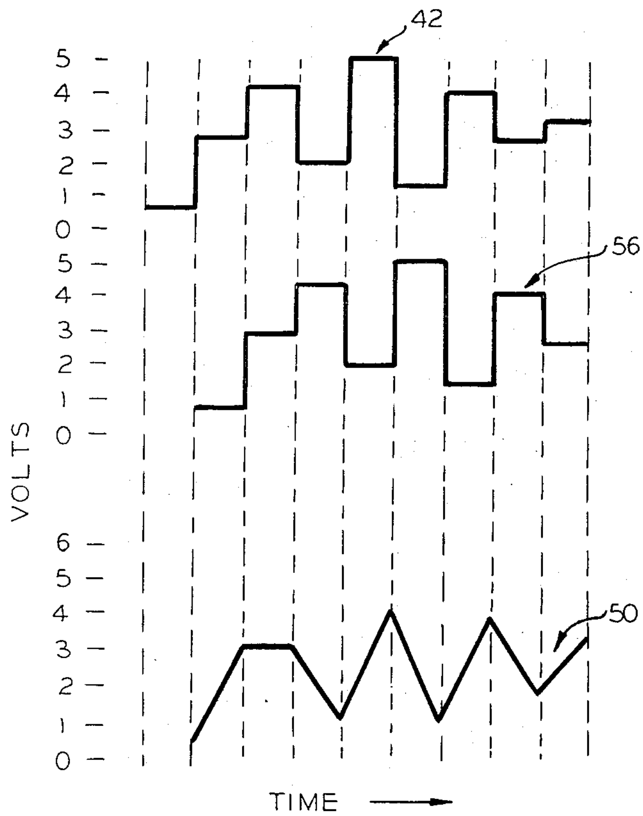



FIG.7

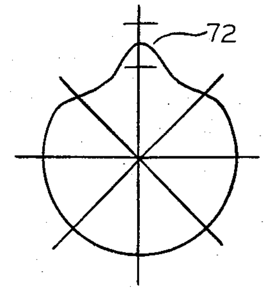



FIG.8

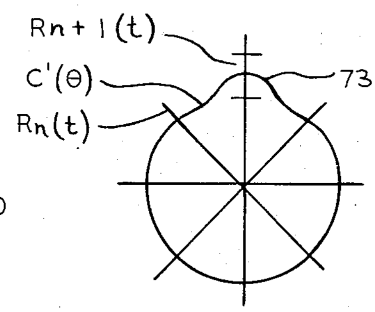



FIG.9

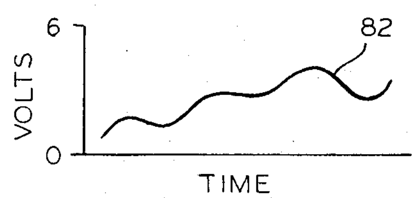



FIG.11

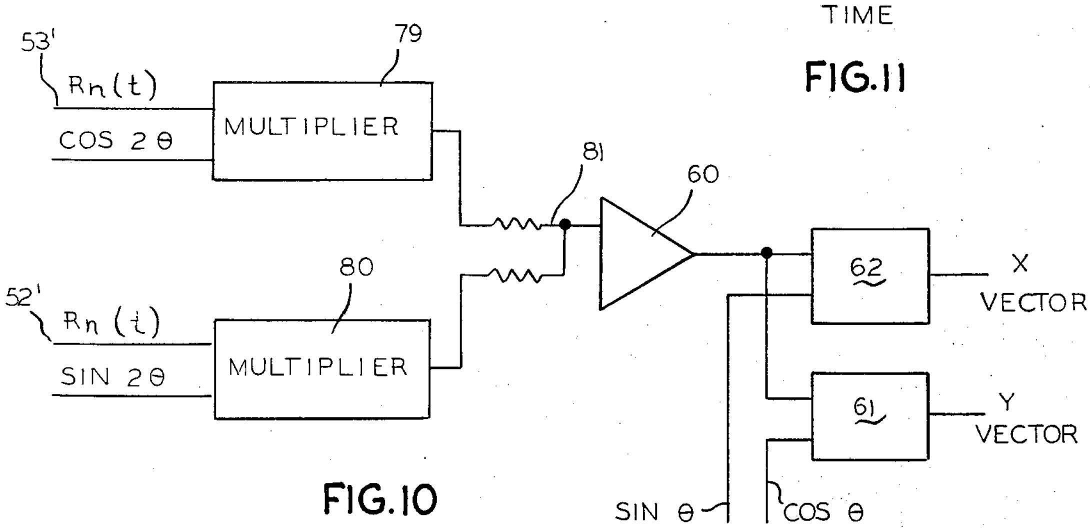



FIG.10

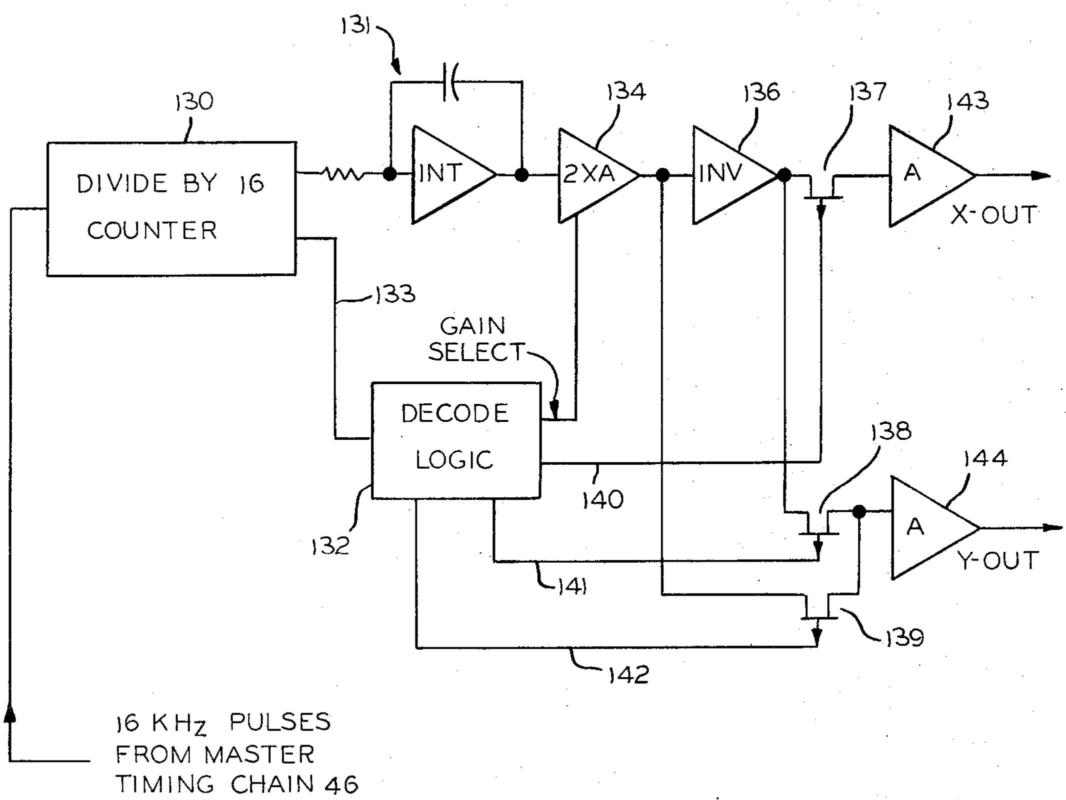

131
130
134
136
137
143
DIVIDE BY 16
COUNTER
INT
2XA
INV
A
X-OUT
133
GAIN
SELECT
DECODE
LOGIC
138
144
140
132
A
Y-OUT
141
139
142
16 KHz PULSES
FROM MASTER
TIMING CHAIN 46

FIG. 12

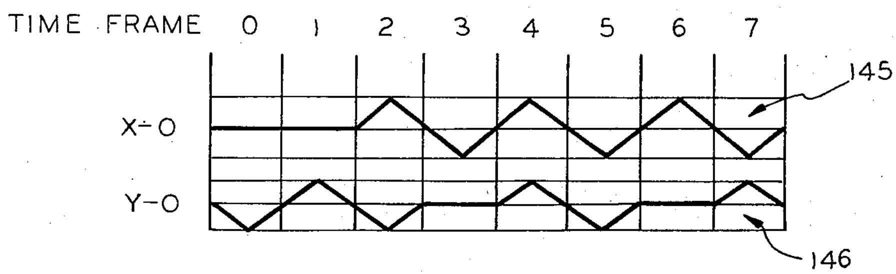



FIG. 13

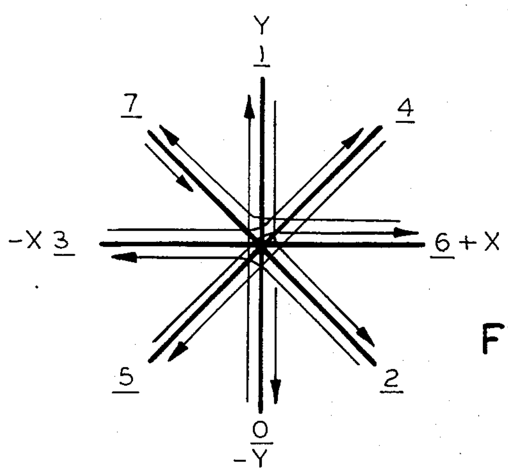



FIG. 14

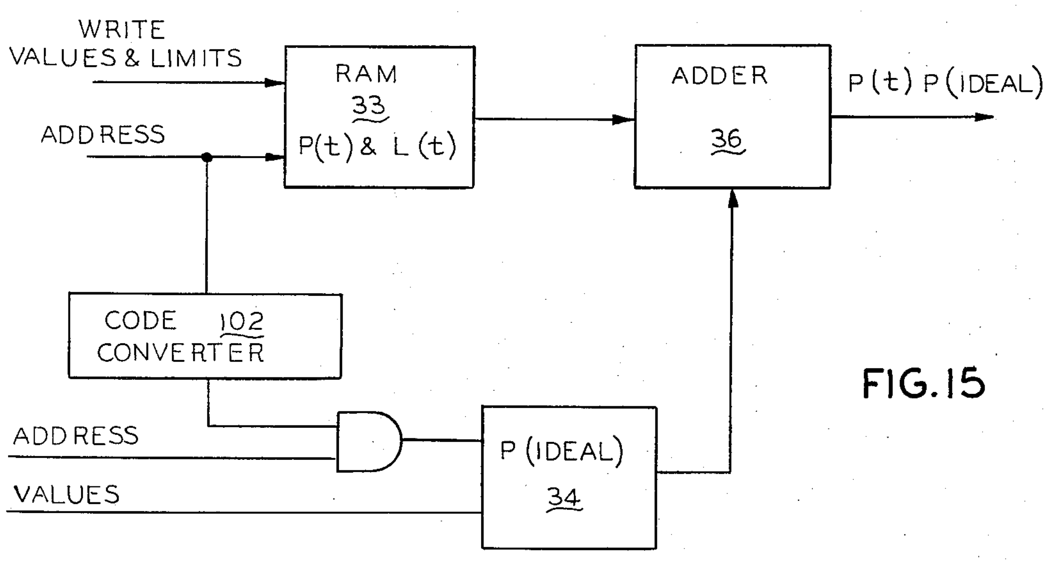



FIG. 15

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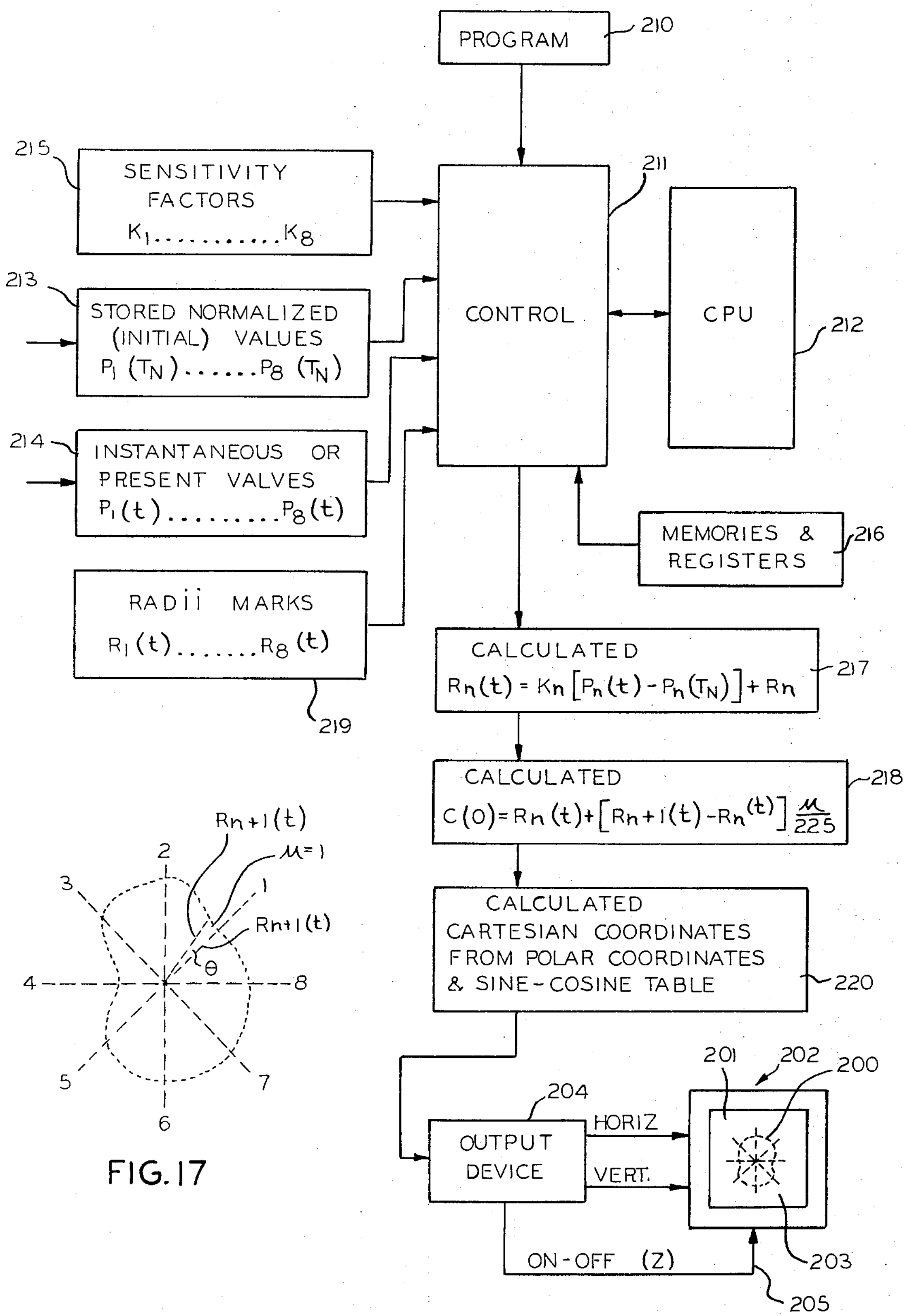


FIG. 16

FIG. 17

# VECTOR CONTOUR PLOT OF PHYSIOLOGICAL PARAMETERS

## BACKGROUND OF THE INVENTION

This invention relates to a method and apparatus for displaying physiological data so that rapid and accurate human interpretation can be made and the indicated therapeutic regimen may be implemented as quickly as possible.

Present physiological data monitoring systems employ sensors which produce signals that are functionally related to a set of measured physiological parameters such as heart rate, blood pressure, premature ventricular contractions per minute, blood pH, respiration rate, partial pressure of blood gases and others. Thsse data are usually displayed on a multitude of instruments such as panel meters, digital displays and analog displays on oscilloscopes. The amount of user interpretation time needed is proportional to the number of parameters displayed. Thus, in clinical situations where it is desired to measure as much physiological information as possible and to continually assess the physiological systems as fast as changes occur, present systems are unsatisfactory.

It has been suggested in the book, *Biomedical Engineering*, H. S. Wolf, World University Library, McGraw-Hill, New York, 1970, that many physiological parameters might be displayed on a single oscilloscope screen as a polar plot. The concept involves representing physiological parameters with individual equiangularly displaced radial vectors which would be modulated in length in proportion to the variations of the parameters. It has also been proposed that tips of the vectors be connected with a trace so as to form a circle when all parameters correspond with normal values and to form a continuous line figure having other contours when one or more parameters departs from normal. The belief was that a circle could be recognized and quickly interpreted as a normal situation and that departures from a circle could also be perceived and quickly interpreted as to the degree and interrelationship of one or more abnormalities.

Until the present invention was made the promising basic concept of a vector contour plot had not been implemented as a clinically useful device. One of the problems was that so-called normal physiological parameters were averages of a healthy population and were not meaningful reference points for monitoring ill patients who might be under intensive care or subject to trauma such as surgery or myocardial infarction. Moreover, even though it is not difficult to modulate individual vector lengths in proportion to the parameter variations, there was a problem of obtaining perceptible variations in vectors or parameters that were represented by large numbers in which there were small percentage changes in the monitored parameter. In other words, adequate distortion sensitivity was not realized for a change to be perceived.

Among other problems which had not been solved was to obtain zero suppressed scaling, which is to say, radiating a vector from a central point which has a value other than zero so that a portion of the parameter scale may be expanded to cover the full length of a normalized vector in which case visualization of small changes is enhanced.

Also not realized up to the present invention were means to permit selective inward scaling and outward scaling of vectors to enhance contour changes with respect to certain physiological abnormalities. And no one had devised a method for showing upper and lower parameter limit markings on a vector contour plot display so that a visual determination could be made as to how near a parameter was to a limit nor was a scheme heretofore conceived for alarming violation of a limit.

Most importantly, a satisfactory method for presenting a continuous contour plot of diverse and possibly simultaneously varying physiological parameters on an oscilloscope tube or as a printed readout had not been implemented.

## SUMMARY OF THE INVENTION

A general object of this invention is to provide apparatus for making a quick and intelligible assessment of a patient's condition primarily by reference to a vector contour plot display on a single soft copy display device such as an oscilloscope screen or on a hard copy display device such as a graph plotter or printer.

Another object of this invention is to provide an algorithm and to implement execution of the same in such manner that a display instrument may be controlled to represent normalized parameter values with any selected degree of distortion sensitivity.

A further object is to provide means for enabling the operator of the new monitoring apparatus to normalize the vector plot on command, that is, to make the physiological data existing at any moment cause a circular plot to be displayed so that ensuing measurements of the parameters will be displayed as changes with respect to normalized values rather than with respect to purported normal or average values.

A still further object is to provide adjustable parameter upper and lower limit markers or ticks for each physiological parameter displayed as a vector contour plot and to provide alarms when a limit is exceeded.

Yet another object is to provide means for indicating on the display screen or on a printed medium when and which physiological parameter is not present so as to minimize the likelihood of the contour plot being misinterpreted.

A further object is to provide means for enabling the monitor user to distinguish contour plot distortions which are indicative of the parameter being a maximum from distortions which are indiCative of the dynamic range of the instrument being exceeded.

Yet another object is to provide means for developing signals that are representative of physiological parameter values, upper and lower parameter limit values and other information that is to be displayed and to process the signals in accordance with an algorithm in a computer or in other digital or analog devices and to use the processed signals to control soft copy or transitory display devices of choice such as phosphor and mosaic screen oscilloscopes and hard copy producing devices such as those which print or plot on paper or other durable medium.

Another object is to provide a converse mode of operation whereby the distorted contour plot representative of the instantaneous values of the patient's physiological parameters may be taken as an initial condition and ideal values may be taken as those which will result in a circular contour plot being displayed when they are achieved incidental to changes in the paient's condition. A corollary to this object is to provide means for the physician to determine and introduce the ideal parameter values.

## DESCRIPTION OF THE DRAWINGS

FIG. 1 is a front elevation of an oscilloscope on which a vector contour plot representative of physiological data is displayed;

FIG. 2 is a block diagram of one system for generating a vector contour plot;

FIGS. 3–5 illustrate some of the contour plots which may appear under certain circumstances on the oscilloscope screen in FIG. 1 or on other display devices;

FIG. 6 shows a square waveform and time associated pulses which are used to facilitate explanation of the vector contour plot generator;

FIG. 7 shows the stepped analog voltage waveforms and a sawtooth waveform constituting an integrated value of the stepped forms and representative of a voltage which fulfills the algorithm and includes the limits;

FIGS. 8 and 9 are particular contour plots which are used to explain certain features of the invention;

FIG. 10 is an alternative circuit for processing the signal which is representative of the algorithm;

FIG. 11 is a waveform analogous to FIG. 7 but has smooth transitions such as may be produced with the circuit in FIG. 10;

FIG. 12 is a block diagram of a system for producing signals that are used to write the fiducial lines in a vector contour plot display;

FIG. 13 shows output signal waveforms from the system in the preceding figure;

FIG. 14 shows with arrowhead lines the sequence in which the fiducial lines are written by the contour display device;

FIG. 15 shows how a part of the circuit of FIG. 2 may be modified to generate a converse contour plot;

FIG. 16 is a diagram for explaining how a vector contour plot may be generated with a computer system; and

FIG. 17 is a contour plot for explaining certain aspects of a computer system.

## DESCRIPTION OF A PREFERRED EMBODIMENT

Refer to FIG. 1 for general orientation to the invention. This figure shows the front of a schematically represented oscilloscope **20** which may be a magnetically or electrostatically deflected type for the purposes of the invention. An oscilloscope is an example of a device which produces a transistory display referred to herein as soft copy. The illustrative scope **20** may haVe a phosphor display screen **21**. Displayed on the screen is a vector contour plot **22** which at the moment is a circle, indicative of all of the physiological data having been recently normalized or of the subject's condition being stable. Contour plot **22** is luminous and is written with the deflected electron beam of the scope **20**. An oscilloscope is an example of a device which produces a real time or transistory display which is referred to herein as soft copy but it is contemplated that hard copy display devices may be used instead of a scope such as high speed printers, chart recorders and others which print on a durable medium such as paper.

There are eight fiducial lines marked **1–8** radiating from the center of circular plot **22**. These lines divide the normalized circle **22** into eight equal sectors or octants, in this example. The fiducial lines may be inscribed on the face of oscilloscope screen **21** or they may be on a transparent mask superposed on the screen or they may be electronically generated with the central intersection point of the lines coinciding with the center of circle **22**. If the system is designed to display more or less than eight physiological parameters the contour plot or the normal circle would be divided into correspondingly more or fewer sectors.

Radially inwardly and outwardly from circular plot **22** are upper limit markers and lower limit markers **23** and **24**, respectively, which are also luminous and are written with the electron beam of the scope **20**. There may be a pair of limit markers or ticks corresponding with each of the fiducial lines **1–8** and hence, with each of the vector represented physiological parameters. The limit ticks may be shifted radially inwardly and outwardly by electronic means in correspondence with setting of the allowable or desired limits for each parameter as will be described later.

The radial distances at which the contour plot **22** crosses the fiducial lines is indicative of the values of the physiological parameters represented by the vectors. In the illustrated device eight parameters are measured. No. **1**, HR stands for heart rate, MABP for mean arterial blood pressure, MVBP for mean venous blood pressure, CO for cardiac output, $pO_2$ for blood oxygen partial pressure, $pCO_2$ for carbon dioxide partial pressure, RR for respiratory rate, and PVC for premature ventricular contractions per minute. These are just typical of the parameters which might be measured and displayed and it should be understood that various other parameters could be substituted. Moreover, the electronics by which the display is realized may be designed to allow display of two to 16 parameter values if desired. Present experience indicates that eight parameter values can be interpreted rapidly and meaningfully.

As implied above, when monitoring of a patient is initiated the equipment is adjusted or normalized and a circular contour plot **22** appears on the screen. In other words, the instantaneous values of the parameters at the start produce a circle which provides a reference or datum. However, the contour plot changes its configuration subsequently in response to variations in the patient's physiological parameters. These changes in configuration or distortions of the plot reveal to the observer the parameters which have changed and the degree of change. Typical contour plots, as they appear after parameters have changed from their normalized or initial set values, may be seen in FIGS. **3**, **4** and **5**.

The oscilloscope console **20** may also have a digital display **25** of the time at which the contour plot was last normalized or circularized and a digital display **26** of the elapsed time from the last normalization.

An important feature of the invention is the development and use of an algorithm which enables presentation of normalized physiological data as a circular contour plot and which reflects changes in a predictable manner. The development of the algorithm will now be presented because it will assist in understanding how several objects of the invention are achieved.

The contour plot has three basic qualities: (1) circularity, (2) non-circularity, and (3) degree of distortion. As a physiological correlation circularity may be used to indicate that the patient's physiological parameters are standard; non-circularity may indicate departure from standard; and, degree of distortion may indicate the severity of the departure. However, as stated above, a table of standard physiological parameters represents average values of a statistically significant portion of the population and may not be meaningful in reference to an unhealthy patient. Thus, in order to realize correlation, all vector parameter scales must be "normalized" such that the physiologically standard values of the eight exemplary parameters must be equidistant from the center along each vector to produce a circular contour plot.

Assuming a linear relation between the vector length, $R(t)$, and its physiological parameer value, $P(t)$, the normalizing function can be written in accordance with equation of a straight line where $A$ and $B$ are constants.

$$R(t) = A \cdot P(t) + B \tag{1}$$

The boundary conditions for the normalizing function are when $P(t) = 0$, $R(t) = 0$; and, when $P(t) = P_N$ then $R(t) = R_N$, where $P_N$ = the normal (standard) physiological value for $P(t)$, and $R_N$ = the preset radius vector length for the normalized circular contour plot. Note that $R_N$ is equal if the eight parameters are to produce a circular plot but $P_N$ is different for each parameter. $(t)$ means that the associated value varies with respect to time.

Applying the boundary conditions to equation (1):

$A = R_N/P_N$ (2) and $B = 0$ (3)

Substituting equations (2) and (3) into (1),

$$R(t) = R_N/P_N\ P(t) \tag{4}$$

which is the normalizing function for correlating with standard parameters.

A disadvantage of the normalizing function in equation (4) is that for a given change in the vector value $P(t)$, $R(t)$ may change little (i.e. $R_N/P_N$ is small) so that the contour plot may be relatively insensitive to a change in $P(t)$.

Now define distortion sensitivity as $dR(t)/dP(t)$.

From equation (4):

Distortion sensitivity $= dR(t)/dP(t) = R_N/P_N$

For example, if $P(t)$ represents systolic blood pressure and $R_N = 2$ inches and $P_N = 120$mm of Hg, the distortion sensitivity of this vector is:

$$dR(t)/dP(t) = R_N/P_N = 2 \text{ inches}/120 \text{ mm} = 0.016 \text{ inches / mmHg} \tag{6}$$

Thus, for a systolic pressure change of 10mm of Hg, the vector length would change by 0.16 inch which may not adequately distort the plot contour to be perceived by an observer.

In order to circumvent this problem the boundary conditions of equation (1) are redefined in terms of "distortion sensitivity." Rewriting the generalized normalizing function of equation (1),

$$R(t) = A \cdot P(t) + B$$

The new boundary conditions are:

when $R(t) = R_N$, $P(t) = P_N$

and $dR(t)/dP(t) = K$ = distortion sensitivity

Applying the boundary conditions to equation (1):

$$R(t) = K[P(t) - P_N] + R_N \tag{8}$$

where

$K$ = distortion sensitivity measured in vector units per parameter units

$P_N$ = normal parameter value

$R_N$ = normalized contour plot vector length

The normalizing function of equation (8) is commensurate with using a zero-suppressed scale for the vectors of the contour plot. That is, the vectors may be either not zero suppressed or zero suppressed where the lowest scale number is greater or less than zero. Zero suppressing allows increasing the distortion sensitivity. Inward and outward scaling are also permitted. However, equation (8) contemplates an absolute value for $P_N$ which is not realistic since the physiological parameters of an unhealthy patient cannot be properly referenced to the average values of a healthy population. Thus, in accordance with the invention, it is desirable to provide means for redefining $P_N$ at any time during the monitoring period of the patient, that is, to allow setting $P_N$, the normalized parameter value, equal to $P(t)$, the present parameter value, at a specific time. Hence, the contour plot can be renormalized to become a circle again and relative changes in parameters can be noticed easily and rapidly. Hence, the operative correlating algorithm becomes,

$$R(t) = K[P(t) - P(T_N)] + R_N \tag{9}$$

where:

$K$ = distortion sensitivity

$P(T_N) = P(t)$ at normalization time $T_N$, and

$R_N$ = normalized contour plot vector length

Means are provided for the operator to redefine $P(T_N)$ at any time and as often as is desired.

In a similar fashion, the algorithm is applied to the limit ticks or markers as expressed in the equation:

$$R_L(t) = K[L(t) - P(T_N)] + R_N \tag{10}$$

where:

$R_L(t)$ = the vector lengths of the limit ticks

$L(t)$ = the limit values

Since it is necessary to connect adjacent vectors together to form a complete vector contour plot, an equation to define the contour between vectors and/or the limits must be provided.

Let:

$R_n(t)$ = any vector expressed by equation (9)

$R_{n+1}(t)$ = the next vector clockwise from $R_N(t)$

A number of infinitesimal straight line segments join the tips of the two vectors to form a curve, the amplitude at any angle $\theta$ between the two tips being designated by $C(\theta)$. The effect of $R_n(t)$ decreases linearly from unity (1) to zero (0) as the angle $\theta$ increases from

0° to 45° if there are eight sectors or octants due to eight parameters being measured. This can be expressed as: $R_n(t)$ (45° − θ°/45°). Similarly $R_{n+1}(t)$ increases linearly from zero to 1 angle as θ increases from 0° to 45°. It is expressed as: $R_{n+1}(t)$ (θ/45°). The equation for the contour of the vectors and limits is the summation of the two parts:

$$C(\theta) = R_n(t)\ [45° - \theta°/45°] + R_{n+1}(t)\ \theta/45° \quad (11)$$

The 45° represents a system using eight vectors or parameters. If $n$ number of vectors are displayd such as 4 to 16, the angle 360°/$n$ would be substituted for 45°.

Attention is now invited to FIG. 2 of the drawings for one example of how the contour plot is developed for display on a viewing screen.

In the lower left of FIG. 2 a physiological information sensor is symbolized by a block marked **30.** This could represent a blood pressure sensor, or an electrocardiograph for heart rate or cardiac output measuring device or any other device for sensing or measuring a physiological parameter. Sensor **30** feeds into a functional unit **31** which for the purposes of one embodiment of the invention may be looked upon as a device that stores binary representations of the measured parameters and set limits and is adapted to be triggered to release the information to a data bus **32** upon receipt of an appropriate signal.

The FIG. **2** system develops analog or digital signals in accordance with equation (9) for controlling a display device such as the $x$-$y$ deflected oscilloscope **20.** The signals representative of equation (9) may also be developed with a computer and they may be used for a raster scan display as will be discussed later.

In FIG. **2,** binary signals representing the physiological parameter values are derived from the functional units such as **31.** There are manually settable means, not shown, associated with each functional unit for producing digital signals representing, for example, upper and lower limits **23** and **24,** which signals are delivered to data bus **32.** The limit signals may also be separately generated by means, not shown, and delivered directly to the place of use in the system rather than through the data bus. Thus, in this example there are eight parameter value digital codes and two limits for each value. Preliminary processing of these signals will be discussed later. For the present, and to enable showing first how the equation (9) algorithm is executed and how the information is displayed, we will assume that the parameter and limit values are written into a random access memory (RAM) **33** which is a large block in the mid-region of FIG. **2.** The limit values $L(t)$ will only change on command. The time variant parameter values $P(t)$ change in response to physiological changes.

There is another RAM **34** into which only the parameter values $P(t)$ are written and stored at normalizing or initializing time $T_N$. Writing occurs when a normalize command decoder **35** is activated manually. As mentioned earlier, normalizing or initializing results in the contour plot **22** becoming circular. The parameter values written into RAM **34** at time $T_N$ remain until normalizing occurs. This permits subtracting the normalized values $P(T_N)$ from the time variable instantaneous parameter values $P(t)$ or limits $L(t)$ so that variations in the contour plot can be produced. $T_N$ appears as renormalization time on indicator **25** in FIG. **1** and allows the operator to ascertain rate of change of the parameters by assessing the amount of distortion over a given time.

The eight time-variable parameter values, $P(t)$, and 16 limit values, $L(t)$, are fed synchronously from RAM **33** to binary adder **36** to which the preset initial parameter values, $P(T_N)$, from RAM **34** are also fed. RAM **34** cycles at three times the rate of RAM **33.** This corresponds to the lower limits, the nominal values and the upper limits. A full adder is used to subtract binary $P(T_N)$ from binary $P(t)$ and $L(t)$. The adder **36** is continuously receiving data from the RAM **33** where it is filed in an orderly fashion. The adder is thus constantly subtracting $P(T_N)$ from $P(t)$ and $L(t)$. However, the parameters written into RAM **33** may be constantly changing and the adder takes a finite time to perform its subtractions. Hence, it is necessary to read out the adder **36** in such fashion as to assure that the parameters and limits are read out when they are not changing and to assure that they are in a proper sequence to cause the oscilloscope **20** writing beam or hard copy producer, not shown, to progress from octant to octant in the same repeatable sequence. This is achieved by use of a latch **37.** The latch is controlled synchronously with RAM **33.** In this embodiment reading and writing are timed in this example with an 8.192 KHz signal **38** whose period is 122 microseconds as shown in FIG. **6.** All reading of the system occurs during the first half of each cycle. At the start of the read cycle, a short pulse **39** such as about one microsecond is produced by means which are not shown. At this time no information is being read into RAM **33.** However, the read start pulse **39** clears latch **37** and lets it read the existing value of $P(t) - P(T_N)$ for one parameter at the falling edge of the pulse. On the next read cycle the next parameter $P_{n+1}(t)$ and the next $P(T_{N+1})$ supplied to the adder are read into the latch **37** and so on until all eight $P(t) - P(T_N)$ values are read after which the process is repeated for the limits. The sequence, in this example, is to read the lower limits, the nominal values and the upper limits. The limit ticks are the result of selective blanking as will be explained.

The digital signals representing the consecutively read parameters and limits are fed to a digital-to-analog converter (D/A) **40** and an analog signal appears on its output **41.** The analog signal has the general form of the plot **42** in FIG. **7.** Each voltage step in plot **42** corresponds with one of the parameters and its limits at the instant of read out and after the $K$ factor and $R_N$ of the algorithm have been introduced as will be explained.

The analog signals are fed into an operational amplifier **43** where each parameter and its associated limits is multiplied by a unique $K$ or distortion sensitivity factor. This is done with a switching device **44.** The switching device is sequenced by binary pulses resulting from addition of 1, 2 and 4 KHz frequencies that are supplied from a timing chain **46** in such manner as to produce a unique binary number for each parameter and its limits. Thus, resistors are sequentially switched into the input of amplifier **43** to change its input resistance and, hence, its gain for each parameter. The output of operational amplifier **43** is thus $K[P(t) - P(T_N)]$.

The last identified signals are fed to a summing amplifier **47.** A voltage adjustment **48** is used to set the size of the initial circular contour plot at the time of a normalization and it does not need to be reset ordinarily. The effect of amplifier **47** is to add $R_N$ which normalizes the contour plot vector length so that the summation with $K[P(t) - P(T_N)]$ for each vector will produce a circle at normalization time even though the vectors have their zero levels suppressed or their scales expanded by the $K$ factor.

The analog output signal $K[P(t) - P(T_N)] + R_N$ from amplifier **47** and the limits $K[L(t) - P(T_N)] + R_N$ for all of the parameter values and limits, respectively, is represented by the stepped analog voltage plot **42** depicted in FIG. **7**. If these abrupt voltage steps were used to drive the oscilloscope **20** or hard copy making device the contour plot would be meaningless. A sawtooth curve such as **50** in FIG. **7** is required and integration is necessary to obtain it. A conventional first order integrator **51**, see FIG. **2**, is used for this purpose. The integrator **51** has two inputs **52** and **53**. There is a sample and hold memory **54** in one of the input lines. It is triggered by a signal, suggested by the arrow **55**, from the timing chain **46** to store the previous parameter values and limits in the set of 24 and the existing set is fed into integrator **51** with the previous set. The new or existing set is represented by the plot **42** in FIG. **7**. The old or stored set is represented by the plot **56** in FIG. **7**. As can be seen, the effect is to delay the old values **56** by one step. The integrator **51** integrates plots **56** and **42** simultaneously, which is to say that it integrates from old values to new values, to thereby connect the values by straight lines as in plot **50** in FIG. **7**. The effect of the integrator is to carry out the connecting of the vectors by a contour line as expressed in equation (11).

The integrated signal is fed into a bound or limiting amplifier **60** in FIG. **2**. This amplifier limits the peaks of plot **50** from going negative or excessively positive. The effect on the contour plot can be seen in FIG. **4** where the tip **70** of the contour plot **22** in the heart rate octant (HR) is flattened. This flattening would occur if the heart rate were way beyond limits in which case the peak is limited by the bound amplifier. Without this clipping or limiting the flattened region **70** would extend to a point and the observer would have no way of knowing whether the contour peaked because the dynamic range of the amplifier had been reached or whether the contour peak was truly representative of the heart rate. Similarly, it is undesirable to let a parameter value go negative so as to let the plot contract beyond center and permit misinterpretation of the contour plot. Thus, negative excursions are not permitted as suggested by the portion of the plot marked **71** in FIG. **4** which only goes to zero and cannot go negative in this example.

The integrated voltage waveform **50** of FIG. **7** is fed to a pair of multipliers **61** and **62** which have $x$ and $y$ output terminals that supply corresponding deflection circuits in the oscilloscope **20** or hard copy device if one is substituted for the scope. Also fed into the multipliers **61** and **62** are sine and cosine wave signals from respective generators **64** and **63**. In a practical embodiment these generators are very stable and are synchronized with clock pulses derived from a suitable timing source. The sine and cosine voltages cause the well known circular Lissajou figure to be traced by the oscilloscope **20** when there is no signal from bound amplifier **60**. When there is a signal representative of the physiological parameter vectors and their limits, the contour plot is distorted, depending on the parameter values, in various ways some of which are exemplified in FIGS. **3**, **4** and **5**.

When the voltage representation of the algorithm has abrupt turning points, as for example in waveform **50** in FIG. **7**, the vector length will vary so as to produce a sharp point on the contour plot at each crossing of an octal or fiducial line by the vectors or limit ticks. In other words, the contour plot or limit ticks do not necessarily cross octal lines at right angles. It depends on the values of the previous and future octal points. An example of a sharply pointed contour is at the first octal line in FIG. **8** where the point is marked **72** and the adjacent limit markers are shown. By using an alternate scheme the limit markers may be made to appear as straight lines and the contour plot can be made to cross each octal line at a right angle. Thus, a pointed contour such as **72** in FIG. **8** will become smoothed and will cross the octal line at a right angle as does the contour at **73** in FIG. **9**.

Right angle crossing of the octal lines by the vector contour is expressed by the following equation and the terms of the equation are labeled on the illustrative contour plot shown in FIG. **9**.

$$C'(\theta) = R_n(t) \cdot |\text{Cos } 2\theta| + R_{n+1}(t) \cdot |\text{Sin } 2\theta| \quad (12)$$

where:

$C'(\theta)$ = any point on the contour between $R_n(t)$ and $R_{n+1}(t)$. See equation (11) also.

$R_n(t)$ = the $n$th vector represented by equation (9) such as **42** in FIG. **7**.

$|\text{Cos } 2\theta|$ = the absolute value of the cosine function.

$|\text{Sin } 2\theta|$ = the absolute value of the sine function.

$2\theta$ = twice the vector rotation frequency.

Equation (12) is executed with the arrangement shown in FIG. **10**. This arrangement does not use the first order integrator shown in FIG. **2**. Instead it feeds the $R_n(t)$ value, see FIG. **9**, on line **53'** from the sample and hold memory **54** to a multiplier **79** and it feeds the $R_{n+1}(t)$ value on line **52'** to a multiplier **80**. The multipliers are conventional 4-quadrant analog devices. In multiplier **79**, $R_n(t)$ is multiplied by $|\text{Cos } 2\theta|$ where $2\theta$ is twice the frequency of the signal fed into multipliers **61** and **62** for generating the Lissajou pattern. $R_{n+1}(t)$ is multiplied by sin $2\theta$ in multiplier **80**. The output signals from the two multipliers **79** and **80** are summed at junction point **81** which is the input terminal to bound amplifier **60**. The amplifier **60** output signal is then multiplied by sin $\theta$ and cos $\theta$ in multipliers **61** and **62**, respectively, and the resultant voltages from the second pair of multipliers, which voltages are shifted 90°, are used for control of the oscilloscope or any other hard copy or soft copy display device which may be used. The algorithm voltage waveform at the summing point **81** in FIG. **10** and the corresponding waveform at the output of bound amplifier **60** has smooth transitions such as are demonstrated by the waveform **82** in FIG. **11** as compared with the sharp transitions of the algorithm waveform **50** in FIG. **7**.

As mentioned earlier in this discussion various schemes may be employed to generate analog or digital representations of the physiological parameter values and their selectable upper and lower limits which can be used to execute the equation (9) vector contour plot algorithm. The discussion started with the assumption that these values were being written in and filed in an orderly manner in a RAM **33** in FIG. **2.** One manner of gathering the values will now be described in reference to FIG. **2** but those skilled in the digital an analog art will appreciate that other methods can be used as well.

In FIG. 2 all of the operations have to be carried on in a definite time relationship with each other so it is necessary to have strobe pulses from which time zero can be reckoned. These strobe pulses appear on the data bus **32** and at various other places in the system. In a commercial embodiment the strobe pulses are based on a master clock, not shown, and are one-fourth second apart. At definite intervals after a strobe pulse occurs the functional units **31** repeatedly and automatically deliver to the bus their digitally coded data or limits in a predetermined sequence. Some sensors **30** and functional units **31** may not be active at a particular moment or may be disconnected in which case they will not produce data and that part of the vector will be missing from the contour plot. How the absence of a vector is indicated on the contour plot will be discussed later. The data bus pulses include, for example, command pulses, waveform pulses, vector pulses, and so forth, in a particular sequence. Each device has a pulse decoder which tells it which information is of use to it and which is to be ignored. This technique is known to those who are versed in the data processing art.

In the illustrative system all present parameter values will occur every quarter of a second and limit values every 2 seconds. Because of the bus size, the parameter values are split into two words which are sent in adjacent data blocks that are separated by 2 milliseconds in this example. A word has eight bits such as parameter status, parameter values, limits, commands, alarms and so forth. A block has 16 words each of which has eight bits and each word has a location.

Near the bottom left of FIG. **2** there are three latches or storage devices **90–92.** Latch **90** receives the first word of parameter data upon receipt of a command signal and the other latch **92** receives the other half on command. At the time latch **92** receives its data, the data from latch **90** is transferred to latch **91.** This prevents problems of RAMs **33** and **34** receiving skewed data. The data from latches **91–92** are available to RAM **33** but are written in only when a write gate **93** is enabled. The separate groups of eight lower limits, eight parameters and eight upper limits all have individual addresses which place them in an orderly file or predetermined sequence in RAM **33** regardless of the sequence in which the data becomes available. Thus, read latch **37** which was discussed earlier can be signaled with a start read pulse **39** to read out the parameters and limits $P(t) - P(T_N)$ in a repeatable sequence.

Since writing information into RAM **33** destroys existing data at the corresponding address, it is desirable not to write into RAM **33** at the same time that it is being read out. Hence, there is a separate read and write half of a full timing cycle for each octant of the vector contour as depicted in FIG. **6.** The sqare wave frequency used in FIG. **6** and in a commercial embodiment happens to be 8.192 KHz or 122 microseconds to read and write for each octant with one-half of the time being assigned to reading coincident with the start of pulse **39** and the other half being for writing when a 3 microsecond write enable pulse **94** occurs as in FIG. **6** well into the write cycle and well after the RAMs and adders have settled. The read and write pulses and the timing frequency come from the timing chain **46** in FIG. **2.** The occurrence of a read start pulse **39** starts the read latch **37** to read all the lower limits at 122 microsecond intervals, then similarly the parameter values are read and finally the upper limits are read in sequence. This happens only when data is not being written in RAM **33** so that only stable and valid data is taken from the adder **36** during read out.

There are two comparators **95** and **96** in the upper left of FIG. **2.** One comparator **95** compares an address with limit addresses on bus **32** and the other comparator **96** compares a timing address with a parameter data address from bus **32.** These comparators operate from a parameter and limit address ROM **107** (read only memory) which selects only the useful parameters and limits for display. When the proper limits coincide with the related parameter value data address in ROM **107,** the limits are written into RAM **33** through the line **97** and the parameter value is written in through line **98** provided that write enable pulses are provided by the write gate **93.**

Since the address on the bus does not necessarily agree with the address of the vector position, a conversion must be made. This conversion is made with a code converter **99.** When code converter **99** senses a parameter such as low limit mean arterial blood pressure (MABP) which is number **2** octant in FIG. **1** of the contour plot on the scope screen or hard copy, but may be the 33 parameter on the data bus, the code converter **99** produces a signal corresponding with number **2** address in the RAM **33** and the data is written if the write gate **93** is enabled.

There is also a two line-to-one line multiplexer **101** which is an electronic double throw switch that permits reading and writing almost simultaneously. The multiplexer **101** switches back and forth between read and write modes with the approximately 8 KHz read and write waveform. Write enable pulses might come along at any time. For instance, the heart rate could change or blood pressure could change in which case there would be a write pulse and new data to be written into RAM **33.** When new data is present on the data bus, write gate **93** is enabled and a write pulse **94** is produced. The timing chain **46** provides sequential read out pulses which are matched with data from the code converter **99** and this results in the proper address for the data being selected in the RAM **33.**

The other RAM **34** stores only the parameter values at time $T_N$, that is, when normalization of the contour plot is commanded. Recall that normalizing the plot means that the parameter values existing at that instant shall form a circle that might be distorted by ensuing changes in parameters. These $P(T_N)$ values are stored in RAM **34** and are furnished to adder **36** until new values are set by renormalization. Until a renormalization command is given the parameter values are inhibited from being written into RAM **34** by an inhibit gate **103.** The gate is opened by a normalize command in which case the values are admitted to RAM **34** from line **98** and they are sent to the proper address therein by a synchronously operated code converter **102.**

Anther heretofore unmentioned item in FIG. **2** is a scavenging circuit shown in block form and marked

104. This device is for clearing RAM 33 at the time of normalizing or renormalizing or start-up. If there is no parameter in a particular address, that address will contain invalid data. The RAMs must be manually cleared. The scavenging circuit operates on three electronic switches 105, 109 and 123 to ground the input lines to RAMs 33 and 34, lock the RAMs in the write mode and hence clear them by cycling through all the RAM addresses so that incoming data in the time of normalizing is valid for both RAMs 33 and 34. This operation takes a small percentage of the normalization period.

A no vector detector is also provided in FIG. 2 and is shown as a block marked 110. When a parameter for one or more octants of the contour plot is missing it is desirable to indicate this on the plot. For example, in the plot shown in FIG. 5 the vector is missing in the fifth and sixth octants and this is indicated by the dashed line 111. Thus, if all zeros are detected in an octant, the no vector detector 110 which is an "and gate," delivers a pulse which is stored or latched in a latch 112 and is further introduced into another "and" circuit 113. Another input 114 has a relatively high frequency applied to it so that when latch 112 is gated synchronously with the octant in which there is no vector, the "and" circuit 113 output interrupts the oscilloscope beam at the frequency applied to input 114 and causes a dashed line such as 111 in FIG. 5 to appear in the appropriate octants. Those skilled in the art will appreciate that missing vectors can also be indicated by dashing the radial fiducial lines which define the vectors or by blanking the appropriate parameter legend.

Also in FIG. 2 is an alarm RAM 115 which is connected baCk to the limit data bus 32 by way of comparator 95. Thus, a signal coming from the data bus indicative of an alarm condition causes the alarm RAM 115 to produce a signal which is latched or remembered in a latch 117 that is operated by synchronizing signals available from the timing circuits. The latch 117 output signal is gated by an "and" circuit 118 to which a low frequency blinking signal is applied on an input terminal 119. The output of "and" circuit 118 is thus a signal which causes the limit markers and that octant of the vector contour to blink on and off and thus call attention of the operator that a limit has been exceeded. Those skilled in the art will understand the fiducial lines can be caused to blink to indicate that the limits have been exceeded. The parameter identifying legend may also be blinked.

A vector and limit tick decoding block 120 is also shown in FIG. 2. The limit markers as generated are really part of a three turn spiral which can be considered roughly as three circles in conjunction with the parameter. The limit markers such as 23 and 24 in FIG. 1, however, are segmented to be noticeable and nonconfusing so the synchronously driven limit tick decoder operates to turn on the limit markers long enough to make limit marks such as 22 and 23 on each octal line inside and outside of the contour plot.

The blinking signal caused by the alarm RAM 115, the dash signal caused by the no vector detector 110 and the limit tick signals caused by decoder 120 are supplied to a four input "or" circuit 121 whose output is the composite vector blanking signal as labeled in FIG. 2 near the top.

The output of a decoder 122 may also be connected to an input of the "or" circuit 121. This decoder is synchronously driven and it can receive digital information for causing fiducial or octal lines to be written by the oscilloscope as well as for causing legends to be written such as the abbreviations for the physiological parameter names or the octal numbers that appear on the scope screen in FIG. 1.

A block circuit diagram of generating the fiducial lines which serve as the axes of the contour plot and divide the plot into octants in this example where eight parameters are displayed, may be seen in FIG. 12. Applicable writing device deflecting waveforms are shown in FIG. 13. The fiducial lines, 0–7, separated by 45°, are shown in FIG. 14 where the light arrowheaded lines indicate the paths of the scope beam or a writing device which may be used to produce hard copy.

In FIG. 12, 16 KHz square pulses are taken from the master timing chain 46 and supplied to a divide-by-16 counter 130. The counter output leading to an integrator 131 is a 4 KHz square pulses in this example. The pulses may lag by 90° the series of 4, 2 and 1 KHz square pulses delivered to a decode logic device 132 via a line 133. The integrator 131 converts the incoming pulses to a triangular wave in a known manner. The triangular wave is selectively switched to generate deflection voltages for two fiducial line lengths, the equal lengths at 0° and 90° and the 0.707 lengths at 45° angles.

The triangular waveform from integrator 131 is supplied to a controlled gain amplifier 134. The 4, 2 and 1 KHz pulse series operate the logic device 132 so as to control the amplifier synchronously between one-gain and 0.707 gain by way of a gain select line 135. The output of amplifier 134 is also supplied to an inverter 136. By selectively switching the triangular wave from amplifier 134 and its inverted version from inverter 136 the waveforms of FIG. 13 are generated.

To enable switching there are three analog switches 137, 138 and 139 in FIG. 12 which may be field effect transistors. They are controlled by respective lines 140, 141 and 142 which deliver switching signals from the decoder 132. Analog switch 137 is in the input of an amplifier 143 which delivers deflection voltages for the $x$-direction to the display scope or other writing device. The analog switches 138-9 are in the input of an amplifier 144 which delivers the $y$-direction deflection voltages. Thus, the amplifiers 143 and 144 are synchronously operated and they repeatedly produce the waveforms 145 and 146, respectively, of FIG. 13.

Those skilled in the art will see how the voltages in the individual time frames 0–7 in FIG. 13 may be summed to produce the beam traces indicated by the arrowheaded lines in FIG. 14. For instance, in the zero and number 1 time frames, in FIG. 13, $x$ voltage is at zero and $y$ goes from zero to the negative limit back to zero and then to the plus limit and back to zero. So the corresponding trace from zero to one is produced in FIG. 14. In time frame number 2, $x$ is at its plus limit and $y$ at its negative limit so the trace down to number 2 in FIG. 14 is produced and so on.

Those skilled in the art will appreciate that any of the fiducial lines of FIG. 1, or octal lines as they may be called if there are eight parameters, may be caused to blink or to be canceled with a properly synchronized blanking signal such as can be derived from the blanking signal gate 121 in FIG. 2. An alarm condition can also be indicated by blinking a fiducial line in the same manner and with the same means described for doing the same to the contour plot itself as was described earlier.

In the system thus far described the contour plot forms a circle initially when the instantaneous values of the parameters are taken as the normal values by instituting a normalize command. This puts a new set of values in RAM **34.** When any physiological parameter departs from initial value of the contour plot distorts from a circle. The system may also be adapted for operating with converse vectors which means that instead of the plot departing from a circle it tends toward reaching a circle. The converse system involves a decision on the part of the physician as to what are the ideal parameters for the patient in a particular condition. These parameters are introduced into the system but, of course, they may not be attained for a time during the monitoring period. At the outset, then, the contour plot will have any shape that is commensurate with the patient's existing physiological parameters. As time goes on the various physiological parameters may change spontaneously or as a result of physician intervention such as for therapy. This may be used by the physician as a criteria for instituting some special treatment of the patient or it might indicate that monitoring may be discontinued. For instance, the physician could introduce a drug which raises or lowers heart rate or oxygen might be administered to change blood $pO_2$ or $pCO_2$ and these parameters and their corresponding vectors would be altered so that there would be zero difference between the preset parameters and the contour representing the parameters. In other words, circularity of the plot with respect to these parameters might be attained showing that the desired status of the patient has been achieved.

A block diagram of part of the circuitry for achieving converse vector operation is shown in FIG. **15** where it will be noted that the components have the same reference numerals and are the same structurally as in FIG. **2** where they were used to describe normalized operation. In FIG. **15**, the ideal or desired physiological values are generated elsewhere and delivered from the data bus **32** over line **150** to the RAM **34.** The limit values too are set manually or on optional command into the other RAM **33.** The limits or markers **24** as they are designated in FIG. **1** only change if they are manually altered by the physician. All other parts of the system are the same and operate the same.

The same basic algorithms apply to the converse contour system as apply to the regular system. The voltage representations of the parameters are expressed by the equation:

$$R(t) = K[P(t) - P(\text{ideal})] + R_N \qquad (9')$$

The representations of the limits are expressed by:

$$R_L(t) = K[L(t) - P(\text{ideal})] + R_N \qquad (10')$$

where $P$(ideal) is the preset parameter or parameters which the pyysician expects the patient to achieve and the other terms of the equations are as previously defined.

The vector contour plot display may be effectuated by various means once the algorithms of equations (9) and (10) are calculated for a set of physiological parameters. The physiological data may be processed in a computer and the results may be used to operate a hard copy or a soft copy visual display device. FIG. **16** is a hybridized partial schematic diagram of computer components and a flow chart which is used to describe the computer method to those skilled in the art.

In the system of FIG. **16** the contour plot **200** is displayed on the phosphorescent faceplate **201** of an oscilloscope **202.** The oscilloscope may be equipped for producing a raster scan and may be magnetically or electrostatically deflected. The oscilloscope beam may also write out or trace out radii such as **203** which emanate from a central point and are equiangularly spaced from each other. For instance, the radii may be 45° apart if there are eight physiological parameters. In one actual embodiment where a raster scan is used there are 777 picture elements in a horizontal line and there are 777 horizontal lines in parallel with each other so the total number of picture elements is the square of the number.

In a raster scan system the contour plot **200** and the radii **203** or fiducial lines and any other data displayed is comprised of dots of light which are produced by turning the beam on and off as it sweeps horizontally and vertically as is well known. The output device **204** interfaces the computer system with the oscilloscope **202** or with any other selected device which may be used to produce a hard or soft copy visual display. Data signals delivered over a symbolized line **205** turn the scope beam on and off as its scan progresses so the contour plot other data can be written point-by-point and will appear as an intelligible composite because the points are produced in such rapid sequence.

In the FIG. **16** system the computer processes physiological data which results in a contour plot that may appear as in FIG. **17** which is used for illustration. The computer has a program symbolized by the block **210,** a control unit **211** and a central processing unit **212.** The various registers and storage devices in these units are not shown for the sake of simplicity.

The computer is supplied with electric signals representative of the one or more physiological parameters which are to be visibly displayed. In this example, eight parameters are assumed. The computer operates on the data by repeatedly computing the algorithm

$$R_n(t) = K_n[P_n(t) - P_n(T_N)] + R_N \qquad (11)$$

where the terms of this equation have the same definition as for equation (9). The lower case $n$ subscripts indicate the number of the parameter which is calculated to produce a vector for that parameter.

As in the previously discussed embodiment the normalized or initial values of the parameters $P_1(T_N)$ to $P_8(T_N)$ are read in and stored as electric signals in a memory **213.** The instantaneous or present values $P_1(t)$ to $P_8(t)$ of the parameters are periodically read in and stored in a memory **214.** Distortion sensitivity factors $K_1$ to $K_8$ are permanently stored in a memory **215.** Thus all of the information which is needed to calculate the equation (11) algorithm is available.

Refer to FIG. **17** for a discussion of how the contour plot is developed. The computer program takes the values of a given parameter and plots the difference between these values and a selected normal value. These differences appear as a change in radius length for one radius on a circle or contour plot divided by eight radii **1–8** in FIG. **17.** The dots in FIG. **17** where the contour plot crosses the various illuminated fiducial lines or radii are the primary values $R_{1-8}(t)$ for each of the parameters. These are calculated in accordance with algorithm (11) and are displayed as light dots within a few microseconds. Initially each radius or vector $n(t)$ is calculated in terms of its polar coordinates and it is converted to cartesian coordinates which establish the positions on the written radii **1–8.** The primary radii marks $R_1(t)$ to $R_8(t)$ are stored in a memory **219** each time they are calculated.

The primary points are connected together by a series of light dots which define linearly interpolated arcs and are called intercontour points for convenience. There are 225 intercontour points spaced 0.2° apart in each octant. These points are calculated by the computer in accordance with the equation:

$$C(\theta) = R_n(t) + [R_{n+1}(t) - R_n(t)](u/225) \qquad (12)$$

where $C(\theta)$ is a contour point in polar coordinates $\theta°$ from the preceding clockwise primary point; $R_n(t)$ is the vector value of the $n$th vector; $R_{n+1}(t)$ is the value of the $(n+1)$th vector; and $u$ is the index angle from point-to-point which is 0.2° in this example. The intercontour points are first computed in terms of polar coordinates which are then converted to cartesian coordinates as was the case with the primary points. The conversion is achieved by using a sine-cosine table which may be stored in a register or memory **216.** An intercontour point is displayed on the scope each time the angle $u$ is indexed. The computer is programmed so that the intercontour points in each octant are calculated and displayed. At the end of each octant the computer determines whether it should go on to the next octant or loop back and start over.

The computer is programmed to write the eight dotted radii as a first step after which the primary and intercontour points are calculated and displayed. Before or after these events the computer may direct the display tube or hard copy printer, if any, to display identifying numbers at the ends of the radii and letters such as HR constituting an abbreviation for heart rate and other letters designating the other parameters may be written too if the computer is properly programmed. Even though the contour plot and other data displayed on the screen are written in dot form and in various sequences, the calculating of the dot positions and their placement is so rapid that the eyes perceive a steady complete picture on the oscilloscope screen.

New and initialized or normalized values $P_1(T_N)$ to $P_8(T_N)$ may be entered into memory **213** at any time in which case the contour display will be restored to a circular shape. As time goes on the circle will remain if no physiological parameter changes or there will be distortion if any do change.

Although embodiments of the new method and apparatus for displaying physiological data have been described in considerable detail, such description is to be considered illustrative rather than limiting, for the invention may be variously embodied and is to be limited only by construction of the claims which follow.

We claim:

**1.** Apparatus for producing a visible contour plot representative of a plurality of presently measured parameter values compared with initially selected parameter values, comprising:

a. first means for receiving a sequence of electric signals which correspond with the respective presently measured parameter values, each signal being designated $P(t)$ and each being representative of a particular parameter value,

b. second means for receiving and storing said sequence of signals at a time characterized as initializing and normalizing time, each such signal for a particular parameter being designated $P(T_N)$,

c. subtraction means for receiving said signals from the first and second means and for sequentially subtracting the signals so that a difference signal corresponding with each parameter is represented by $[P(t) - P(T_N)]$,

d. means for adding to each signal for a parameter a selectable constant value $R_N$ where $R_N$ equals the predetermined vector radius length for a normalized circular contour plot, thereby producing a final set of signals which are each represented by $[P(t) - P(T_N)] + R_N$ which is a vector designated $R(t)$, the instantaneous signal value representative of each parameter in a sequence including all of the signals, and

e. display means for receiving said signals $R(t)$ and for producing visible representations thereof about respective intersecting axes which axes correspond with each parameter.

**2.** The apparatus set forth in claim **1** including:

a. means for multiplying each difference signal, $[P(t) - P(T_N)]$, respectively, by a predetermined unique sensitivity factor $K$ so as to produce a sequence of signals in which each parameter is represented by $K[P(t) - P(T_N)]$ for thereby producing a final set of signals which are each represented by $K[P(t) - P(T_N)] + R_N$ when $R_N$ is added to each signal.

**3.** The invention set forth in claim **1** including:

a. means for producing electric signals corresponding with predetermined limits of said respective parameter values, said limit signals being introduced in said first means and being designated $L(t)$,

b. said limit signals each also having subtracted therefrom in said subtraction means in sequence a corresponding initial parameter value $P(T_N)$ to produce difference signals represented by $[L(t) - P(T_N)]$,

c. said adding means also adding to each of the last named signals the selectable constant value $R_N$ to produce a sequence of signals represented by $[L(t) - P(T_N)] + R_N$ which is a vector designated $R_L(t)$, the instantaneous limit values for each parameter in a sequence, said signals $R_L(t)$ being displayed substantially concurrently with said parameter representing signals $R(t)$.

**4.** The apparatus set forth in claim **3** including:

a. means for multiplying each difference signal, $[L(t) - P(T_N)]$, respectively, by a predetermined unique sensitivity factor $K$ to produce a sequence of signals in which said limits are represented by $K[L(t) - P(T_N)]$ for thereby producing a final set of limit signals which are each represented by $K[L(t) - P(T_N)] + R_N$ when $R_N$ is added to each signal.

**5.** The invention set forth in claim **1** including:

a. switching means selectively operable to switch initial parameter value representing signals $P(T_N)$ into said second storage means.

**6.** The invention set forth in claim **3** wherein:

a. said display means comprises writing means operable in response to parameter and limit signals and including means for effecting visible writing on a medium, and including
b. first and second multiplier means for receiving said sequence of $R_L(t)$ and $R(t)$ signals and being coupled with said display means,
c. a cosine waveform signal generator connected to one multiplier means and a sine waveform signal generator connected to another of said multiplier means, said sine and cosine waveforms having the frequency designated $\theta$, the final sets of signals also being supplied to each of said multiplier means, the output of said multiplier means constituting voltages, respectively, controlling said writing means, said waveform generators being for causing a Lissajou circle to be plotted on said medium when said parameter corresponding signals in said final set are equal and said plot being non-circular when any signal in said final set is not equal to the others.

**7.** The invention set forth in claim **6** wherein:
a. said display means comprises an oscilloscope.

**8.** The apparatus set forth in claim **1** including:
a. latch means for receiving the output difference signals from said signal subtracting means in a predetermined sequence, and
b. means for inhibiting said second storage means from receiving parameter value representing signals when said latch means is accepting difference signals from said subtracting means.

**9.** The apparatus set forth in claim **1** wherein:
a. said second and first signal receiving means are adapted to stor digital signals and said subtraction means is adapted to process digital signals,
b. latch means receiving the output digital difference signals from said subtraction means, said latch means being responsive to consecutive reading control signals by reading the instantaneous difference signals in a repeatable sequence from said subtraction means, and
c. a digital-to-analog converter receiving the digital output signals from said latch means and converting said signals to a sequence of analog signals.

**10.** The apparatus set forth in claim **9** including:
a. first order integrator means connected to the output of said means for adding a selected constant signal value, $R_N$, to each in the set of difference signals, said integrator means converting said analog signals from a stepped waveform to a smoothed waveform.

**11.** The apparatus set forth in claim **6** wherein:
a. said means for subtraction is adapted to process digital signals,
b. a digital-to-analog converter,
c. means for producing read initiating signals,
d. latch means adapted to respond to consecutive read signals by gating said digital difference signals in a predetermined sequence to said converter, said converter producing a sequence of analog signals corresponding with the difference signals,
e. third and fourth multiplier means, the third being adapted to multiply a new sequence of signals by Sin $2\theta$ and the fourth being adapted to multiply a near preceding old sequence of signals by Cos $2\theta$, where $2\theta$ is twice the frequency of $\theta$,
f. means for summing the output signals from said third and fourth multipier means, and
g. means for applying said summed signals simultaneously to said first and second multiplier means and concurrently with the signals at frequency $\theta$ from said sine and cosine waveform generators.

**12.** The apparatus set forth in claim **1** including means for producing fiducial lines dividing said plot into sectors in said display where said fiducial lines are equiangularly spaced from each other, said fiducial line producing means comprising:
a. means for generating consecutive pairs of control signals occurring in time frames, respectively, equal in number to the number of fiducial lines to be written,
b. means for coupling said control signals simultaneously to said display means, said display means responding by displaying said fiducial lines.

**13.** Apparatus for producing a visible contour plot representative of a plurality of presently measured parameter values, comprising:
a. first means for receiving a sequence of electric signals which correspond with the respective presently measured parameter values, each signal being designated $P(t)$ and each being representative of a particular parameter value,
b. second means for receiving and storing a selected sequence of signals which correspond respectively with prospective parameter values and are designated $P(\text{ideal})$,
c. subtraction means for receiving said signals from the first and second means and for sequentially subtracting the signals so that a difference signal corresponding with each parameter is represented by $[P(t) - P(T_N)]$,
d. means for adding to each signal for a parameter a selectable constant value $R_N$ where $R_N$ equals the predetermined vector radius length for a normalized circular contour plot, thereby producing a final set of signals which are each represented by $[P(t) - P(\text{ideal})] + R_N$ which is a vector designated $R(t)$, the instantaneous signal value representative of each parameter in a sequence including all of the signals, and
e. display means for receiving said signals $R(t)$ and for producing visible representations thereof about respective intersecting axes which axes correspond with each parameter.

**14.** The apparatus set forth in claim **1** including:
a. a first order integrator means having as one input an existing final set of electric signals and as another input a previously existing final set of signals, said integrator means integrating the existing and next preexisting signals to produce an electric signal waveform having sharp transition points coincident with each parameter,
b. a pair of electric signal multipliers each having an input for simultaneously receiving said electric signal waveform,
c. a sine wave signal generator supplying its signal to another input to one of said multipliers,
d. a cosine wave signal generator supplying its signal to another input to the other of said multipliers,
e. the output signals from said multipliers being applied to said display means.

**15.** The apparatus set forth in claim **1** including:

a. a sine wave signal generator and a cosine wave signal generator, whose output signals have a frequency $\theta$,
b. a multiplier having an input for said sine wave signals and another multiplier having an input for said cosine wave signals,
c. sine and cosine wave signal generators whose output signals have the frequency $2\theta$,
d. a second pair of multipliers each having at least two inputs, an input of one receiving the sine $2\theta$ signals and a corresponding input of the other receiving the cosine $2\theta$ signals,
e. the multiplier in the second pair receiving said sine $2\theta$ signals also receiving the next preexisting signals $R_n(t)$ representative of said parameters,
f. the multiplier in the second pair receiving said cosine $2\theta$ signals also receiving the existing set of signals $R_{n+1}(t)$ representative of said parameters,
g. means summing the output signals from said second pair of multipliers, and
h. means applying the summed signals to each of said first pair of multipliers, whereby to produce a smooth transition set of electric signals for driving said display device.

**16.** The invention set forth in claim **1** including:
a. means for detecting the absence of a signal in said sequence of signals which corresponds with the absence of a parameter, and
b. means responsive to said detecting means for interrupting said visible representation of said absent signal on said display device.

**17.** The invention set forth in claim **1** including:
a. means for detecting the absence of a signal in said sequence of signals, which corresponds with the absence of a parameter, and
b. means responsive to said detecting means for interrupting the visible display of an axis associated with that part of said contour plot for which the parameter signal is absent.

**18.** The invention set forth in claim **3** including:
a. means for detecting a signal indicative of a parameter limit having been exceeded,
b. and means responsive to said detecting means for controlling said display means to repeatedly interrupt the display of said limit signal which corresponds with the parameter which has been exceeded.

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UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,811,040 Dated May 14, 1974

Inventor(s) Phillip T. Weinfurt et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 19, claim 9, paragraph "a", line 35, change spelling of "stor" to---store---.

Column 20, claim 13, prefatory clause, line 22, after "values" insert---compared with initially selected parameter values---.

Column 20, claim 13, paragraph "c", line 36, after "by" delete $[P(t) - P(T_N)]$ and substitute--- $[P(t) - P(\text{ideal})]$---.

Signed and sealed this 8th day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents