United States Patent [19]

Sigworth

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[54] **IMPEDANCE PLETHYSMOGRAPH**

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[21] Appl. No.: **388,541**

Related U.S. Application Data

[63] Continuation of Ser. No. 190,900, Oct. 20, 1971, abandoned.

[52] **U.S. Cl.** .... **128/2.1 Z;** 128/2.05 V

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

[58] **Field of Search** ..... 128/2.05 P, 2.05 R, 2.05 V, 128/2.08, 2.1 M, 2.1 P, 2.1 R, 2.1 Z, 145.5–148, 419 P, 419 R, 421, 422, 2.05 F, 2 L

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3,149,627	9/1964	Bagno	128/2.1 Z
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3,593,718	7/1971	Krasner et al.	128/419 P
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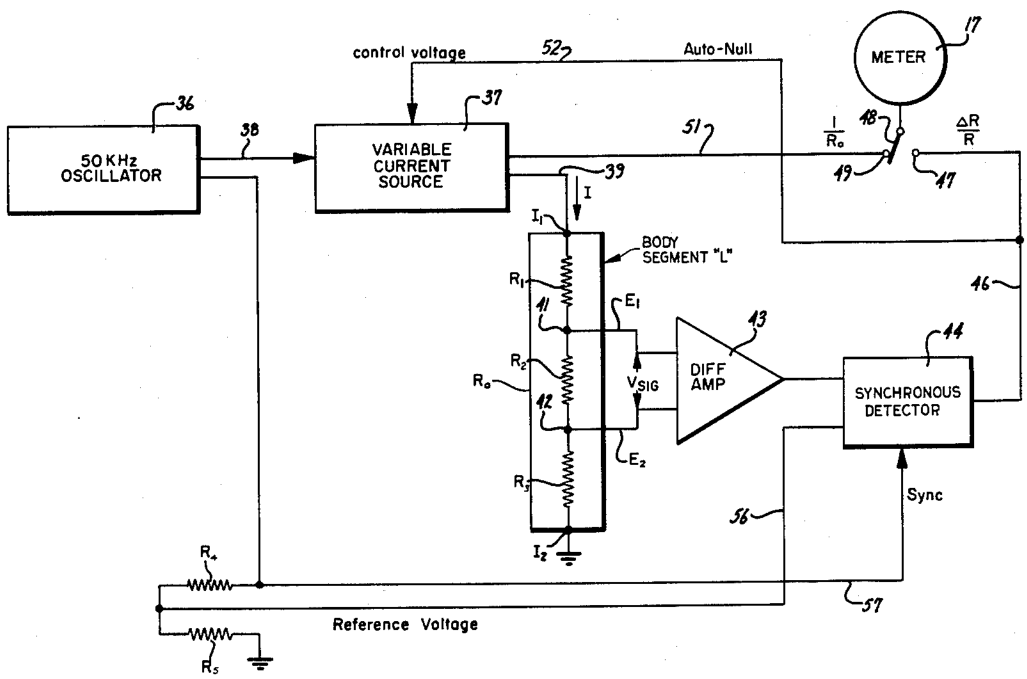
[57] **ABSTRACT**

Plethysmograph having current and voltage electrodes with a variable current source connected to the current electrodes to supply varying current to a biological segment to provide a voltage which is utilized to provide a signal which represents a percent of change of resistance of the biological segment.

5 Claims, 4 Drawing Figures



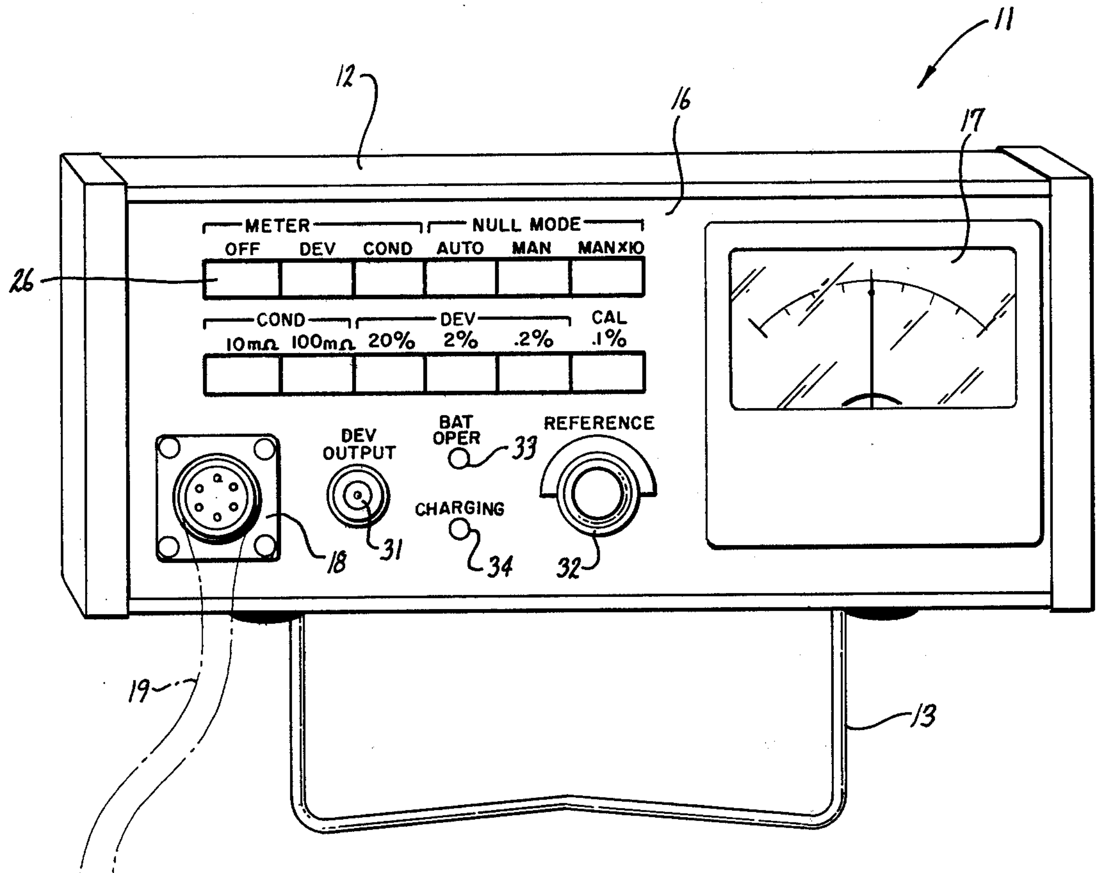
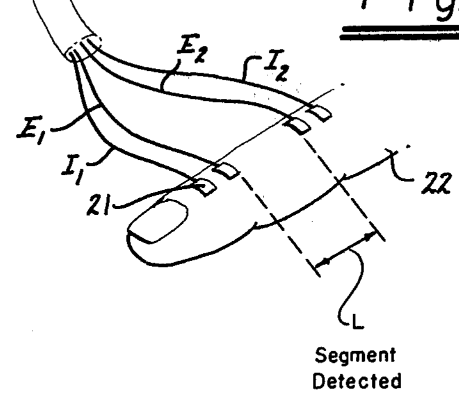


Fig. 1



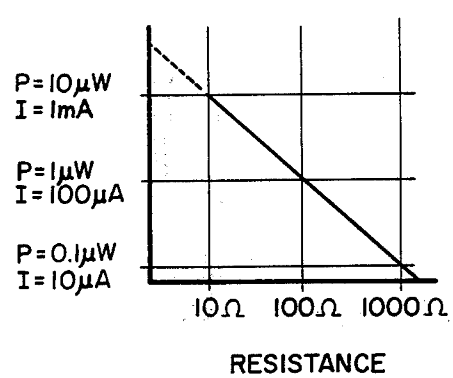


Fig. 3

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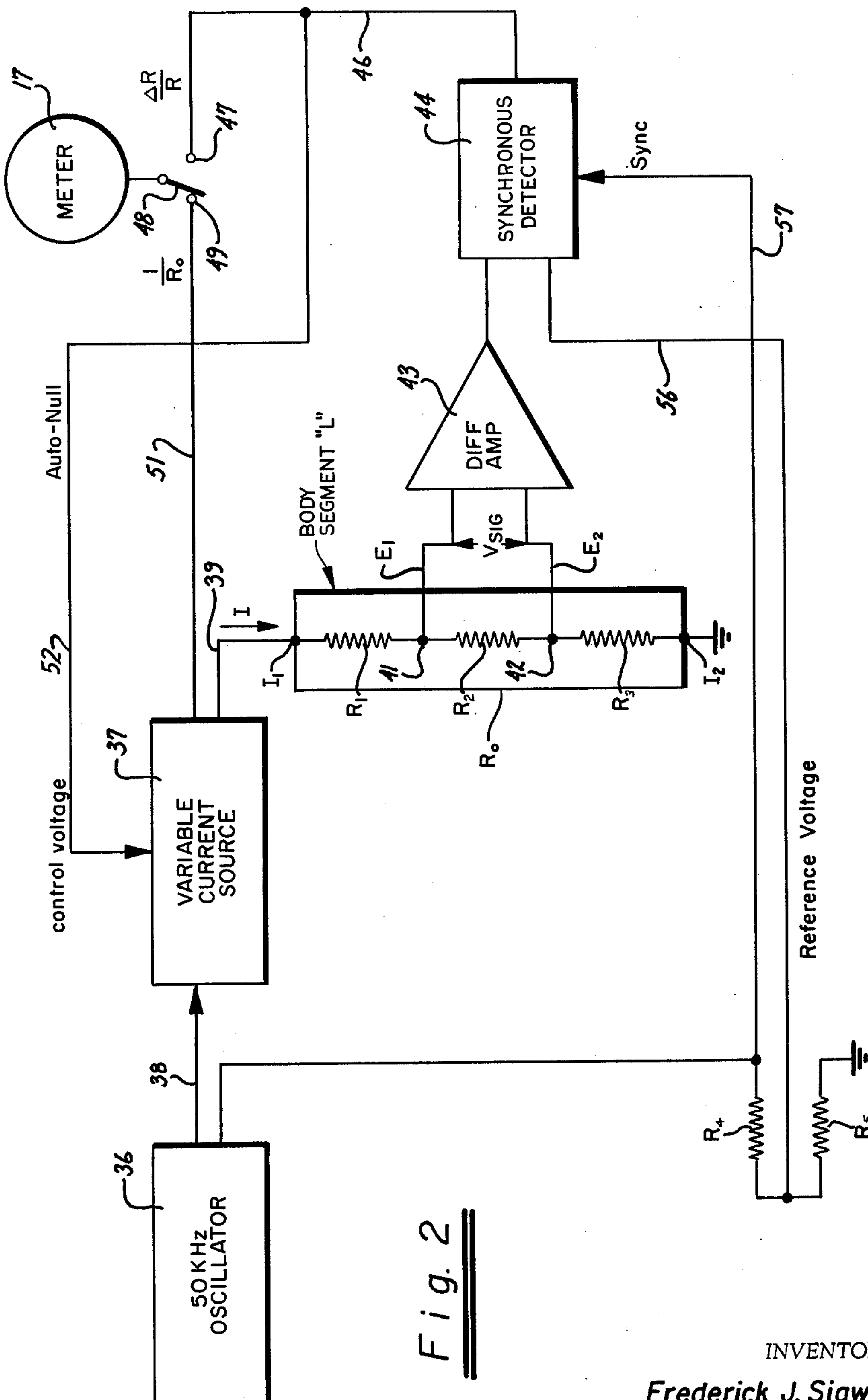

Fig. 2

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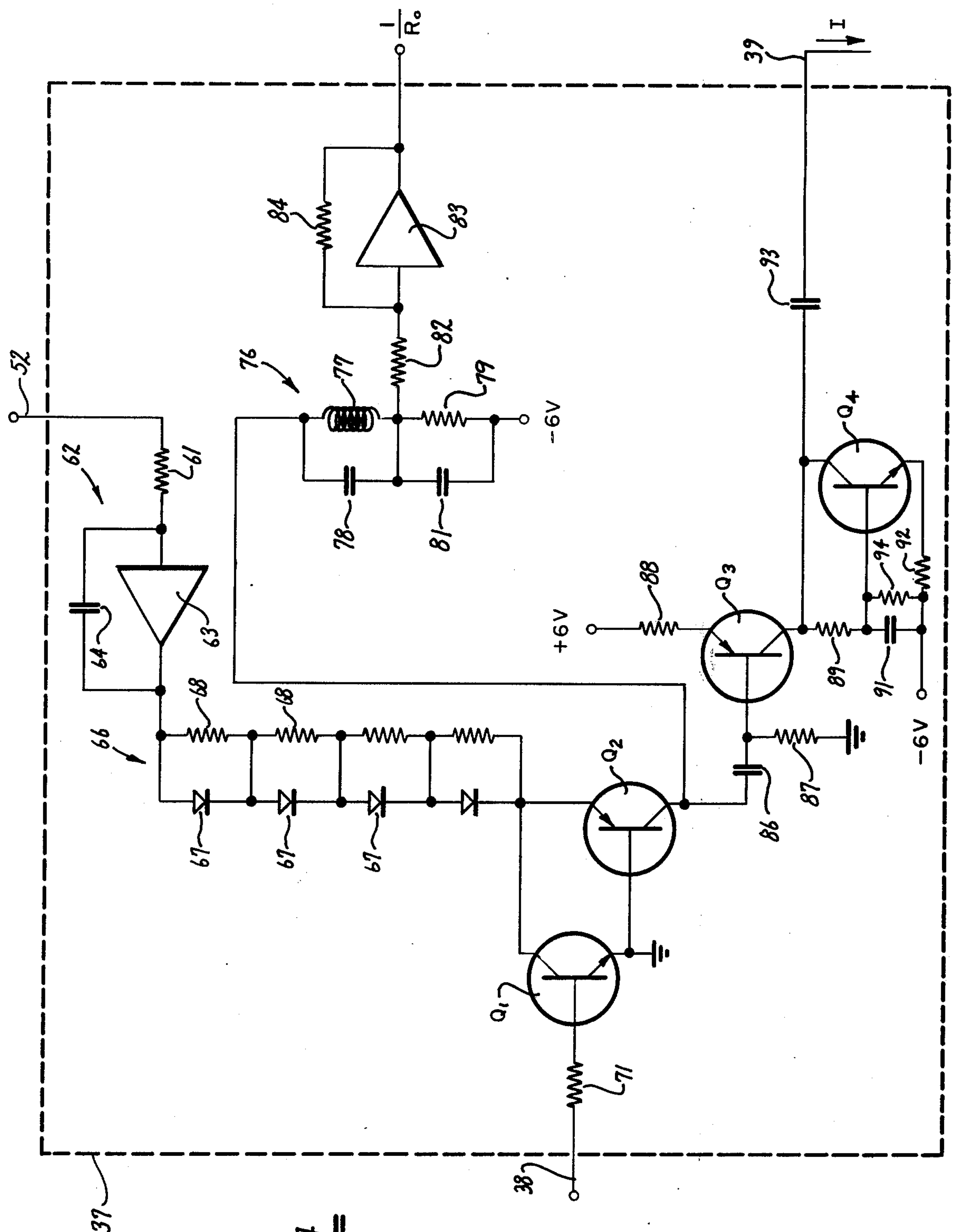

Fig. 4

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IMPEDANCE PLETHYSMOGRAPH

CROSS REFERENCES

This is a continuation of application Ser. No. 190,900, filed Oct. 20, 1971, now abandoned.

BACKGROUND OF THE INVENTION

In U.S. Pat. No. 3,149,627, there is disclosed a plethysmograph which can be utilized for making impedance measurements on biological segments. A bridge arrangement is provided which must be manually nulled. Because the variations in resistance in the biological segments are very small as, for example, on the order of 0.1% or less, it is very difficult to null the meter because of drift. There is, therefore, a need for a new and improved plethysmograph.

SUMMARY OF THE INVENTION AND OBJECTS

The plethysmograph consists of firs: and second current electrodes and first and second voltage electrodes adapted to be applied in pairs across the biological segment with one current electrode adjacent one voltage electrode and the other current electrode adjacent the other voltage electrode. A high frequency oscillator is provided. A variable current source is connected to the output of the oscillator and to the current electrodes so that an oscillatory current is supplied to the current electrodes. Amplifier means is coupled to the voltage electrodes for measuring the difference voltage developed across the voltage electrodes. Means is coupled to the amplifier and to the high frequency oscillator for detecting the output of the amplifier using the output of the oscillator as a reference. Means is provided for supplying the output of the detector means to provide a control voltage for the variable current source to automatically null the same. The output of the detector produces a signal which represents a percent of change of the resistance of the biological segment.

In general, it is an object of the present invention to provide an impedance plethysmograph which is quite accurate and reliable.

Another object of the invention is to provide a plethysmograph of the above character which is relatively easy to operate.

Another object of the invention is to provide a plethysmograph which can provide a readout in either percent of deviation or in conductance.

Another object of the invention is to provide a plethysmograph of the above character in which an automatic nulling function is provided.

Another object of the invention is to provide a plethysmograph of the above character which can be battery operated.

Another object of the invention is to provide a plethysmograph of the above character in which the readout is in percent variation rather than an absolute resistance indication.

Additional objects and features of the invention will appear from the following description in which the preferred embodiment is set forth in detail in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view of an impedance plethysmograph incorporating the present invention connected to a body segment.

FIG. 2 is a block diagram of the impedance plethysmograph.

FIG. 3 is a graph showing current flow for various values of resistance.

FIG. 4 is a detailed circuit diagram of the variable current source in FIG. 2.

DESCRIPTION OF PREFERRED EMBODIMENT

The impedance plethysmograph incorporating the present invention is in the form of an electronic instrument **11** as shown in FIG. **1** which includes a case **12.** The case **12** is provided with a stand **13** so that the front panel **16** of the instrument can be elevated above the top surface of a table or other support provided for the instrument. A meter **17** is mounted in the front panel and is capable of measuring percent deviation according to the deviation scaling selected as hereinafter described. It is also capable of reaing millimhos according to the scaling mode selected as hereinafter described. The front panel is also provided with a connector **18** which is connected to a cable **19.** The cable **19** is provided with four conductors which have been identified as first and second current electrodes I_1, I_2 and first and second voltage electrodes E_1, E_2 shown in FIG. **1** and which are preferably color coded in a suitable manner. For example, the conductors I_1 and I_2 can be color coded red, whereas the conductors E_1 and E_2 can be color coded black. Each of the conductors which are provided, I_1, I_2 and E_1, E_2 is connected to relatively thin metallic strips **21** formed of a suitable material such as aluminum. These strips serve as electrodes which are secured to the biological segment L of which the measurements are to be made such as a human body segment in the form of a finger **22** by suitable means such as an adhesive tape (not shown). The electrodes are arranged in pairs across the body segment L with one current electrode adjacent one voltage electrode and the other current electrode adjacent the other voltage electrode. Thus, electrodes I_1 and E_1 are adjacent to each other and the electrodes E_2 and I_2 are adjacent to each other.

A total of **12** pushbuttons **26** are arranged in two spaced parallel rows, the function of which will hereinafter be described. Three output jacks are provided as a part of the instrument in which one of the jacks **31** is provided on the front panel. These jacks are simultaneously active. The front jack **31** provides deviation, that is, recording resistance change related to blood or gas volume variation. The two rear jacks (not shown) provide a derivative signal which is the rate of change of the deviation signal and a conductance signal which monitors the relatively slow changes in the conductance of the examined segment during change in posture or in response to vasodilation or vasoconstriction. A reference potentiometer **32** is mounted on the front panel. In addition, two lights **33** and **34** are provided. Light **33** indicates that the instrument is on battery operation and light **34** indicates that the battery is being charged.

A block diagram of the electronic circuitry within the case **12** is shown in FIG. **2.** As shown therein, it consists of an oscillator **36** operating at a suitable frequency as, for example, 50 kilohertz (KHz). The oscillator **36** supplies a timing signal through a conductor **38** to a variable current source **37.** The variable current source supplies on output line **39** an output current which is related in amplitude to the control voltage which is supplied to the current source. This output current is identified by the letter I and is fed into the body segment L which is represented by the resistance R_0 consisting of three resistors R_1, R_2 and R_3 in series. R_1 and R_3 represent the contact resistance between the electrodes I_1 and I_2 and the skin of the body member to which the electrodes are secured. Two taps **41** and **42** are provided on opposite sides of the resistor R_2 and correspond to the two electrodes connected to the conductors E_1 and E_2. The conductors E_1 and E_2 are connected to a differential amplifier **43** which measures the difference voltage developed across the body segment resistance R_2 and is indicated as V_{sig}. The output of the differential amplifier **43** is supplied to a synchronous detector **44.** The detector **44** has an output **46** which is connected to a terminal **47** of a switch **48** that has an additional terminal **49.** The switch **48** is connected to the meter **17.** When the switch **48** is connected to the terminal **47,** it will be reading the resistance changes in the body segment itself which is supplied by the synchronous detector. When the switch is connected to the terminal **49** which is connected to the variable current source **37** by conductor **51,** the meter will be reading the conductance of the body segment itself by measuring the amount of current that the current source is putting into the body segment. The output of the synchronous detector is also supplied to the variable current source by a conductor **52** to provide a control voltage as hereinafter described.

A referance voltage is supplied to the synchronous detector **44** through the conductor **56** which is connected between two serially connected resistors R4 and R5 that form a voltage divider network connected between ground and the oscillator **36.** A synchronizing voltage is supplied to the synchronous detector **44** from the oscillator **36** by a conductor **57.**

By way of example, the reference voltage supplied to the synchronous detector can be on the order of 100 millivolts. If the voltage supplied by the differential amplifier is greater than 100 millivolts, the output of the synchronous detector is positive and if the voltage from the differential amplifier is less than 100 millivolts, then the output from the detector **44** is negative. Thus, the detector **44** provides a d.c. voltage which gives information as to whether or not the output of the differential amplifier is above or below the null point. Thus, there is supplied a control voltage to the variable current source which performs an automatic nulling function. Thus, when the output from the synchronous detector **46** is negative, the variable current source **47** will be instructed to supply an additional voltage across the body segment to increase the current flow through the body segment. Conversely, if the output of the synchronous detector **44** is positive, the variable current source will be instructed to supply a lesser voltage to the body segment to thereby decrease the current flow through the body segment. It can be seen that this is similar to nulling a bridge where the differential signal voltage developed across the body segment is compared with an internal reference voltage. In the present nulling system, the current supplied to the body segment itself is varied which means that the voltage level developed across the body segment is a long term constant, although short-term small changes in the body segment resistance will show up as variations superimposed on the 100 millivolt output from the differential amplifier and, therefore, will show up as instantaneous variations in the output of the synchronous detector **44.**

The control of the current passing through the body segment L to provide a nominally constant voltage makes it possible for the output read on the meter **17** to represent the percent of value change rather than absolute resistance. Thus, for example, if the body segment resistance is 100 ohms, it would develop a 10 millivolt signal across the body segment which requires 0.1 of a milliampere to pass through the body segment resistance. The 10 millivolts across the body segment is picked off by the conductors E_1 and E_2 and amplified as, for example, ten times in the differential amplifier **43** to provide the 100 millivolt output to the synchronous detector **44.** The relatively slow response time of the control voltage ensures that the current level will remain constant for short-term variations. If there is an instantaneous change of resistance in the body segment, as for example, by 0.1 ohm, this would mean a change in the signal voltage measured across the body segment of the 0.1 ohm times a 0.1 of a milliampere or 10 microvolts of change at the output of the synchronous detector **44.** The synchronous detector **44** would then amplify by a suitable gain such as 1,000 to provide 100 millivolts of signal which is supplied to the meter **17** which would show a variation of 0.1%, i.e., 0.1 of an ohm out of 100 ohm.

If the segment resistance is 50 ohms instead of 100 ohms, then in order to obtain 100 millivolts at the input to the detector or 10 millivolts at the input to the differential amplifier,, the feedback loop would cause the current source to supply 0.2 of a milliampere of current to the body segment. Then if there is 0.1% change in the resistance of 50 ohms which would be 0.05 ohms, the current level would be double which would provide the same 10 microvolts of signal being supplied to the differential amplifier and thus eventually would result in the same 100 millivolt signal to the meter **17.**

In FIG. **3,** there is a curve which shows the current and power involved in the measurement process with current and power variations. The X-axis shows body segment resistances from 10 ohms to 1 k. The Y-axis shows both the power and current involved in the body segment at each resistance. A logarithmic scale is used in both axes. As shown in the graph, there were 100 microamperes of current flowing through the body segment when the body segment had a resistance of 100 ohms. If the body segment resistance instead of being 100 ohms is 10 ohms, the feedback loop would change the variable current source **37** until the current level would be 1 milliampere and the power would be 10 microwatts.

The chart shows that the current level is inversely proportional to the body segment resistance. It also shows that only very small current and power levels are required for making the desired measurements, so small that no sensation is felt or health hazard is encountered by use of the device.

Of the blocks shown in FIG. **2,** the oscillator **36,** the differential amplifier **43** and the synchronous detector **44** are of a conventional type. By way of example, the synchronous detector **44** can be like the phase sensitive detector **15** disclosed in U.S. Pat. No. 3,149,627.

A detailed circuit diagram of the variable current source **37** is shown in FIG. **4.** As shown therein, the control voltage from the detector **44** is supplied through the lead **52** to an integrator **62** consisting of an amplifier **63**, a resistor **61** and a capacitor **64** which is connected between the input and the output of the amplifier **63**. The output of the integrator **62** is supplied to a log function generator **66** of a type well known to those skilled in the art which consists of a plurality of serially connected diodes **67** and a plurality of serially connected resistors **68** with one of the resistors **68** being connected across each of the diodes **67**. The log function generator **66** produces a voltage across the same which is the logarithm of the current flowing through the log function generator. The use of the log function generator makes it possible for the system to have a constant response time regardless of the body segment resistance and the current level that is fed into the segment L. Transistors Q1, Q2, Q3 and Q4 are provided in the circuit shown in FIG. **4**. They are all of a conventional type and each includes base, collector and emitter elements as shown.

The **50** KHz signal from the oscillator **36** is fed onto the line **38** through a resistor **71** to the base of a transistor Q1 which serves as a switching transistor for switching the signal supplied by the log function generator away from the transistor Q2 for nominally half of the time. The other half of the time Q1 is turned off under the control of the signal supplied on the line **38** and all of the current through the function generator is supplied to the emitter of the transistor Q2. The result is that a square wave current output is supplied by the collector of Q2.

The square wave output from the collector of the transistor Q2 is supplied to a tuned circuit **76** which is resonant at the same frequency as the oscillator **36** and consists of an inductance **77** and a capacitor **78** connected across the inductance. The tuned circuit **76** converts the square wave into a uniform sine wave. The current exciting the tuned circuit **76** is also supplied through a sampling resistor **79** for the conductance readout by the meter **17**. A capacitor **81** connected across the resistor **79** serves as a bypass capacitor. The resistor **79** is connected to a −6 volt source as indicated in FIG. **4**. The resistor **79** measures the average value of current flowing through the log function generator **66** and through the transistor Q2 and through the inductance **77**. This current is proportional to the output current from the entire current source **37**. This current is supplied through a resistor **82** to an operational amplifier **83** which has a resistor **84** connected between the input and the output of the amplifier **83**. The output of the amplifier is connected to a terminal which is identified as $1/R_o$ which is adapted to be connected to the meter **17** to provide a conductance readout on the meter **17**.

The 50 KHz sine wave signal developed across the tuned circuit **76** is also supplied through a capacitor **86** to the base of a current source transistor Q3. The base is also connected to ground through a resistor **87**. The emitter of the transistor is connected to a +6 volt supply voltage through a resistor **88**.

The collector of the transistor Q3 is connected through a resistor **89** to the base of a transistor Q4. The base of Q4 is also connected through a capacitor **91** and a resistor **94** to a −6 volt source as indicated in FIG. **4**. The emitter of the transistor Q4 is connected through a resistor **92** to the −6 volt source. The collector is coupled through a capacitor **93** to the current output line **39** which is connected to the resistor R_o as shown in FIG. **2**.

The transistor Q4 and its associated components, capacitors **91** and **93**, serve as a d.c. current source to provide operating bias for the transistor Q3. The output impedance of the current source is high, limited only by the collector impedances of Q3 and Q4 and the value of resistor **89**.

The instrument is provided with a battery which is not shown. Means is also provided in the instrument for charging the battery when the instrument is not in use. Circuitry is provided which is associated with the pushbuttons **26** on the front panel so that switching from the off button to either the conductance or the deviation button disconnects the instrument from the a.c. power supply and switches to battery power. The battery operating light **33** will turn on if the battery is operational. When the instrument is not in use, it can be connected to an a.c. power outlet. Pushing the off button will activate the battery charging circuit and the light **34** will be lit.

Additional circuitry is provided which is connected to the other pushbuttons which are utilized in connection with the operation of the instrument as hereinafter described.

Let it be assumed that it is desired to make an impedance measurement of a body segment as, for example, of one finger as shown in FIG. **1**. The electrodes are applied by adhesive tape as hereinbefore described and positioned in the manner shown in FIG. **1**.

Now let it be assumed that it is desired to operate the instrument in the manual balancing mode. If the segmental resistance (E_1 - E_2) is below 100 ohms, the deviation button, the manual button and the 20% deviation mode button should be pushed. The reference potentiometer **32** is adjusted for a zero center reading on the meter **17**. Alternatively, the 2% and 0.2% buttons can be pushed to obtain finer tuning by the use of the reference potentiometer **32**.

When the segmental resistance is above 100 ohms, the "manual × 10" button is pushed and the reference potentiometer is switched from zero to a 1,000 ohm scaling. The deviation can be read directly from the meter **17** according to the scaling (20%, 2%, 0.2%), or the deviation may be displayed on an oscilloscope or recorded on a laboratory recorder by connecting the same to the deviation jack **31** provided on the front panel. When the conductance button is pushed, the conductance in millimhos can be read on the meter. The reference potentiometer **32** reads directly in ohms. Thus, in a manual mode, the potentiometer **32** reads from zero to 100 ohms. In the manual × 10 mode, the potentiometer **32** reads zero to 1,000 ohms. The reading on the reference potentiometer **32** corresponds with the conductance reading on the meter **17**.

Let it be assumed that automatic null operation is desired. When this is the case, the deviation button, the automatic null button and one of the deviation scaling buttons (20%, 2%, 0.2%) should be pushed. The deviation can be read directly from the meter **17** or displayed on a laboratory recorder from the output jack **31** as hereinbefore described. When the conductance button is pushed, the conductance can be read directly off the meter or displayed on a laboratory recorder from the output jack provided on the back side of the instrument. Nulling is performed automatically in the automatic mode and the reference potentiometer is not used in the automatic null configuration.

In practice, it may be desirable to determine the resistance from the reference potentiometer **32** by using the instrument either in manual or manual × 10 mode and then switching to the automatic null mode to obtain conductance.

During these measurements, it should be appreciated that since the instrument is being operated from a battery, there is no possibility of supplying voltage to the patient. In addition, it should be appreciated that the voltage and currents which are being applied to the biological segments of the patient are so low that they will not cause any harm.

In the diagram shown in FIG. **2,** the meter **17** is connected to $1/R_o$ terminal which corresponds to the condition when the conductance button is pushed. The meter **17** registers the body segment conductance which is reciprocal of the resistance. Thus, when automatic nulling is taking place, the current passing through the body segment is inversely proportional to the segment resistance. Therefore, the current supplied into the body segment is proportional to the segment conductance. The monitoring voltage which is supplied at the $1/R_o$ terminal shows the amount of current which is being supplied to the body segment which can be read out directly on the meter **17.** The meter **17** is provided with two scales. The meter normally rests in the center of the two scales. One scale is in deviation and provides deviation in percent in both directions. The second scale is calibrated in millimhos of conductance from zero to 10 or zero to 100 millimhos depending upon which pushbutton is pressed.

The measurements hereinbefore described by the use of the four electrode impedance plethysmograph makes it possible to measure changes in electrical resistance related to blood and gas volumes in biological segments. During each cardiac cycle as blood is distributed from the heart to various organs and tissues, the new blood volume results in a change in resistance which increases current conduction from the plethysmograph and results in a pulsatile voltage output which can be detected and recorded for qualitative and quantitative evaluation.

In a similar manner, increases and decreases in gas volume during respiratory activity result in variations in electrical resistance of the thoracic segment which can be detected and recorded as an index of pulmonary function.

The high frequency current from the plethysmograph penetrates through superficial and deep body structures, and each segment defined by the placement of electrodes may be interpreted as a homogeneous volume conductor having a measure of resistance referred to as the base line resistance.

This measured segmental resistance is influenced by the pulsatile, gas or blood volume variations as well as increases or decreases in total blood or body tissue fluid within the segment which may occur during vasoconstriction, vasodilation or postural variation. The impedance plethysmograph is capable of recording both the pulsatile changes (deviation) and variations in base line resistance which is registered as the reciprocal conductance.

In summary, the basic principle utilized by the impedance plethysmograph depends upon changes in the electrical characteristics of tissue during each cardiac or respiratory cycle as a new volume of blood or gas enters the segment. In terms of pulsatile blood volume changes, the conductive properties of the segment and the new volume of blood parallel each other during systole and create a change in resistance which is proportional to the pulse volume. Variations in resistance occur in the thoracic cavity during respiration as a result of the difference between blood and gas volumes in the chest during respiratory activity.

The impedance plethysmograph offers the clinician, medical specialist, educator or biologist and researcher a reliable, easy to use and highly versatile electronic instrument. The plethysmograph output can be connected to oscillographs and pen recorders for simultaneous recording of ECG and changes in blood pulse volume and respiratory volume of biological segments. The use of the impedance plethysmograph does not cause trauma to the patient. The system does not require venous occlusion or methods for detecting small and large changes in electrical resistance related to blood pulse volume variations and is useful in defining pulmonary gas volume when electrodes are positioned over the thorax area.

The impedance plethysmograph can be useful in medical schools for teaching principles of cardiovascular and pulmonary physiology, in hospitals for the management of patients pre- and post-operatively, in animal and clinical diagnostic laboratories for drug evaluation, and in offices of the general practicioner for early detection of cardio-vascular disorders. The deviation output (ΔR) is located on the front and rear panels. The base line (conductance) and the derivative $d(\Delta R/R)/d_t$ outputs are available at the rear panel for simultaneous recordings. The selector pushbuttons activate the meter for additional monitoring of all three simultaneous recorder outputs.

It is apparent from the foregoing that there has been provided an impedance plethysmograph which has many desirable features. It is portable and it is simple to operate. It can be operated in either manual balancing or automatic balancing modes.

The incorporation of a constant current source of variable output as a nulling element in the impedance plethysmograph is particularly important because it makes it possible to provide a readout which is a percent of the percent variation rather than an absolute resistance indication on a meter.

I claim:

1. In a plethysmograph first and second current input electrodes, first and second voltage drop measuring electrodes adapted to be applied in pairs across a biological segment with one current electrode adjacent one voltage electrode and the other current electrode adjacent the other voltage electrode, an oscillator having a high frequency output, a variable current source connected to the oscillator and to the first and second current input electrodes for receiving a timing signal from the oscillator so that an oscillatory output current is provided to the current input electrodes, amplifier means coupled to said first and second voltage drop electrodes for receiving the voltage developed across said voltage drop electrodes and producing an output responsive thereto, means for providing a predetermined reference voltage, means coupled to the amplifier means for detecting the output of the amplifier means and providing an output responsive thereto, said means for detecting receiving said predetermined reference voltage, means for supplying the output of the means for detecting to the variable current source to provide a control voltage for the variable current source so that the output from the variable current source provides an output from the amplifier means matching said predetermined reference voltage, the output of said means for detecting providing a percent deviation signal which represents a percent of change of resistance value of the biological segment, indicating means for receiving the percent deviation signal from the means for detecting for indicating the percent of change of resistance, said indicating means also being for indicating conductance of the biological segment, and means for alternately connecting said indicating means for receiving the output of the variable current source.

2. In a plethysmograph first and second current input electrodes, first and second voltage drop measuring electrodes adapted to be applied in pairs across a biological segment with one current electrode adjacent one voltage electrode and the other current electrode being adjacent the other voltage electrode, an oscillator having a high frequency output, a variable current source connected to the oscillator and to the first and second current input electrodes for receiving a timing signal from the oscillator so that an output oscillatory current is provided to the current input electrodes, amplifier means coupled to said first and second voltage drop electrodes for receiving the voltage developed across said voltage drop electrodes and producing an output responsive thereto, means for providing a predetermined reference voltage, means coupled to the amplifier means for detecting the output of the amplifier means and providing an output responsive thereto, said means for detecting receiving said predetermined reference voltage, means for supplying the output of the means for detecting to the variable current source to provide a control voltage for the variable current source so that the output from the variable current source provides an output from the amplifier means matching said predetermined reference voltage, the output of the means for detecting providing a percent deviation signal which represents a percent of change of resistance value of the biological segment, and indicating means calibrated in terms of two quantities, one of said quantities being conductance and the other of said quantities being percent of resistance change, together with means for connecting said indicating means alternately to said variable current source and said means for detecting respectively.

3. In a plethysmograph first and second current input electrodes, first and second voltage drop measuring electrodes adapted to be applied in pairs across a biological segment with one current electrode adjacent one voltage electrode and the other current electrode being adjacent the other voltage electrode, an oscillator having a high frequency output, a variable current source connected to the oscillator and to the first and second current input electrodes for receiving a timing signal from the oscillator so that an output oscillatory current is provided to the current input electrodes, amplifier means coupled to said first and second voltage drop electrodes for receiving the voltage developed across said voltage drop electrodes and producing an output responsive thereto, means for providing a predetermined reference voltage, means coupled to the amplifier means for detecting the output of the amplifier means and providing an output responsive thereto, said means for detecting receiving said predetermined reference voltage, means for supplying the output of the means for detecting to the variable current source to provide a control voltage for the variable current source so that the output from the variable current source provides an output from the amplifier means matching said predetermined reference voltage, wherein said current source includes a logarithmic function generator electrically coupled between the control voltage input and the oscillatory current output so that the plethysmograph will have a constant response time regardless of the biological segment resistance and the current level supplied to the biological segment, the output of the means for detecting providing a percent deviation signal which represents a percent of change of resistance value of the biological segment, and indicating means for receiving the percent deviation signal from the means for detecting and for indicating the percent change of resistance.

4. In a plethysmograph, first and second current input electrodes, first and second voltage drop measuring electrodes adapted to be applied in pairs across a biological segment with one current electrode adjacent one voltage electrode and the other current electrode being adjacent the other voltage electrode, an oscillator having a high frequency output, a variable current source connected to the oscillator and to the first and second current input electrodes for receiving a timing signal from the current input electrodes, said variable current source including at least two active electronic amplification means connected in series and providing an output impedance which is high with respect to the impedance of the biological segment so that plethysmograph calibration will not be substantially affected by changes in the impedance of the biological segment, amplifier means coupled to said first and second voltage drop electrodes for receiving voltage developed across said voltage drop electrodes and producing an output responsive thereto, means for providing a predetermined reference voltage, detecting means coupled to the amplifier means and to the means for providing a predetermined reference voltage for detecting the output of the amplifier means and providing an output responsive thereto, means for supplying the output of the detecting means to the variable current source to provide a control voltage for the variable current source so that the output from the variable current source develops a voltage across said first and second voltage drop electrodes which provides output from the amplifier means automatically nulling said predetermined reference voltage, the output of the detecting means providing a percent deviation signal which represents a percent of change of the value of resistance of the biological segment, a plurality of serially connected diodes and a plurality of serially connected resistors with one of said resistors connected across each of said diodes included in said variable current source for providing a voltage thereacross which is the logarithm of the current therethrough, whereby a constant system response time is obtained regardless of biological segment resistance or current source output level, and indicating means for receiving the percent deviation signal from the means for detecting and for indicating the percent of change of resistance.

5. In a plethysmograph, first and second current input electrodes, first and second voltage drop measuring electrodes adapted to be applied in pairs across a biological segment with one current electrode adjacent

one voltage electrode and the other current electrode being adjacent the other voltage electrode, an oscillator having a high frequency output, a variable current source connected to the oscillator and to the first and second current input electrodes for receiving a timing signal from the oscillator so that an oscillator output current is provided to the current input electrodes, amplifier means coupled to the voltage drop electrodes for receiving the voltage developed across the voltage electrodes and producing an output responsive thereto, means coupled to the amplifier means for detecting the output of the amplifier means and providing an output responsive thereto, means for supplying the output of the means for detecting to the variable current source to provide a control voltage for the variable current source so that the variable current source provides an output producing a long term constant voltage across the first and second voltage drop electrodes, said variable current source including a logarithmic function generator for providing a constant output response time over a range of biological segment resistance values covering substantially two orders of magnitude, the output of the means for detecting providing a percent deviation signal which represents a percent of change of resistance value of the biological segment, and means connected to receive the percent deviation signal for indicating the biological segment percent change of resistance.

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