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[54] AUDIBLE BLOOD PRESSURE MONITOR

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[52] **U.S. Cl.** ..... **128/2.05 A**

[51] **Int. Cl.** **A61b 5/02**

[58] **Field of Search** ..... 128/2.05 A, 2.05 D, 2.05 F, 128/2.05 G, 2.05 M, 2.05 P, 2.05 Q, 2.05 R, 2.05 T, 2.06 A, 2.06 F, 2.06 R, 2.1 A

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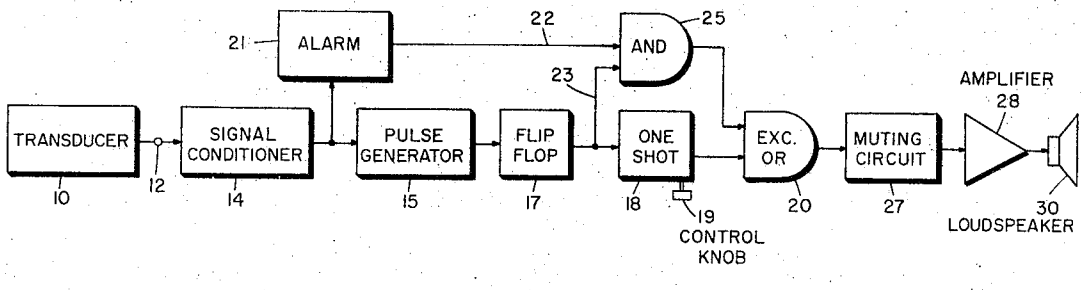
Attorney—Plante, Arens, Hartz, Hix & Smith, Bruce L. Lamb and William G. Christoforo

[57] **ABSTRACT**

A first train of pulses whose pulse repetition frequency and pulsewidth are proportional to blood pressure is generated. A second pulse train of constant width pulses synchronized with the first train of pulses is also generated. The pulsewidth of the pulses in each train are adjusted to be equal at some normal valve of blood pressure. The two pulse trains are then subtracted, one from the other, and the resultant signal is used to drive a loudspeaker to produce an audio signal. The pitch of the audio signal is proportional to blood pressure deviation from the normal and any rhythmic variation in pitch is proportional to heart beat rate.

An alarm circuit includes a capacitor which is charged by variations in blood pressure characteristic of heat beats. In heart beat ceases the capacitor is discharged and one of the pulse trains is blocked from the subtraction circuit so that the resultant audio signal is a loud monotone signal which decays as blood pressure drops.

6 Claims, 5 Drawing Figures



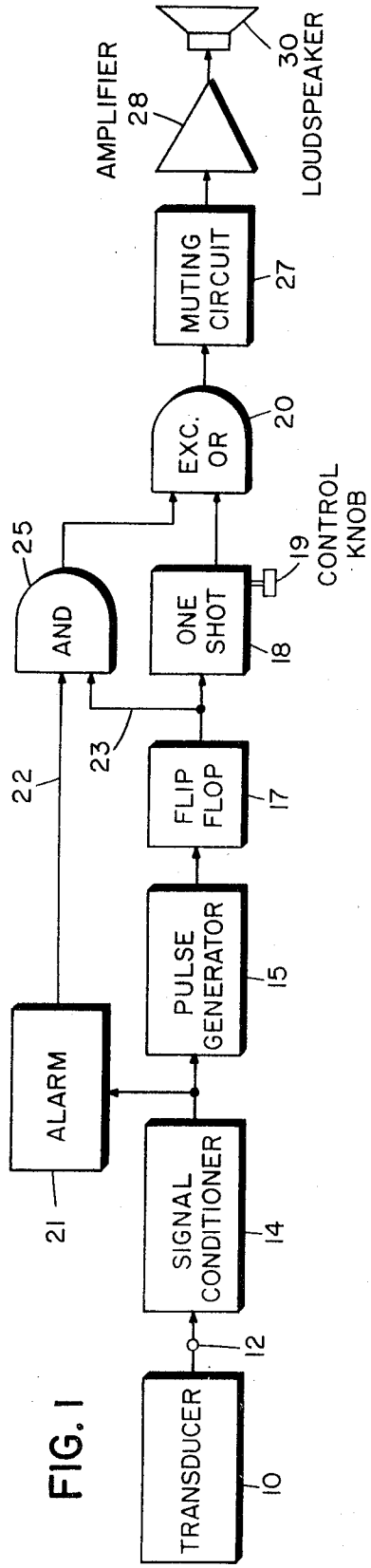


FIG. 1

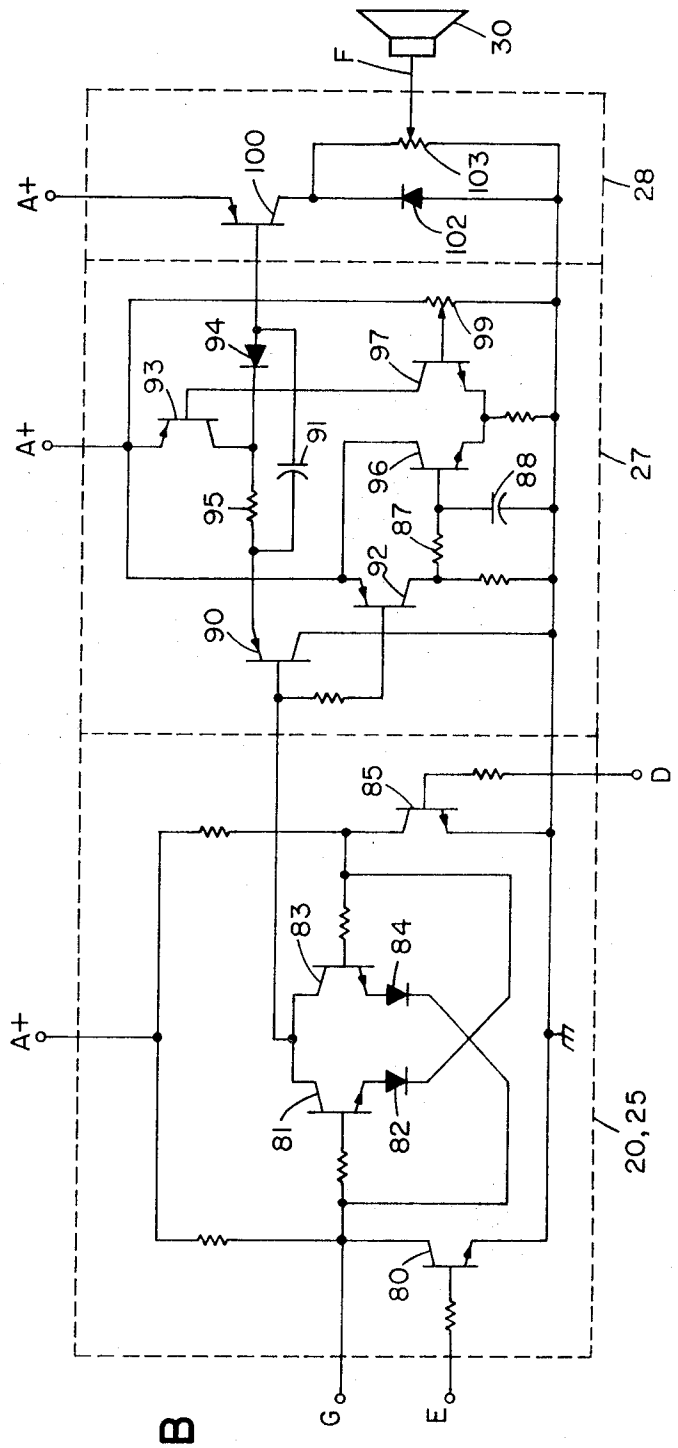


FIG. 2B

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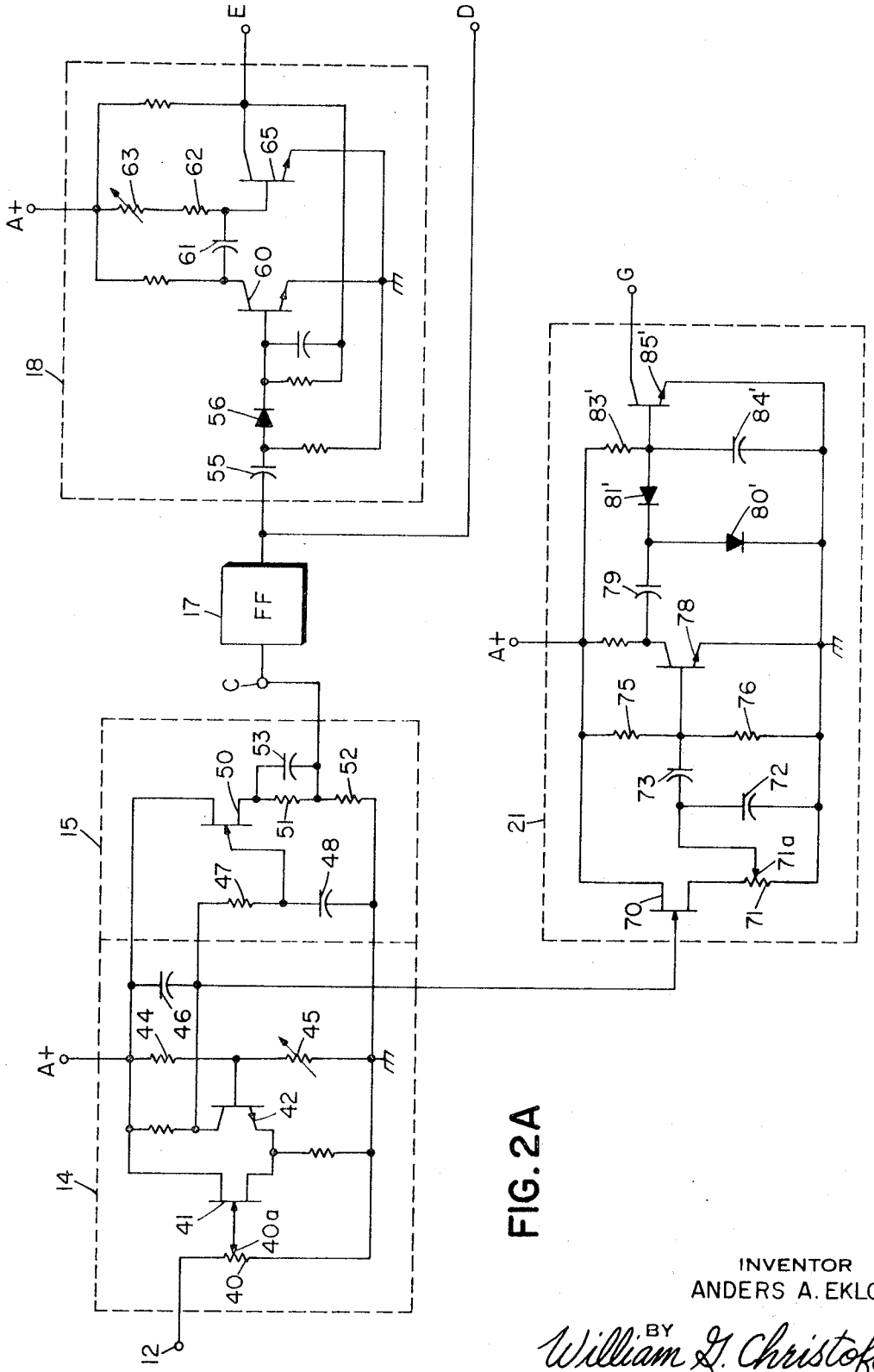


FIG. 2A

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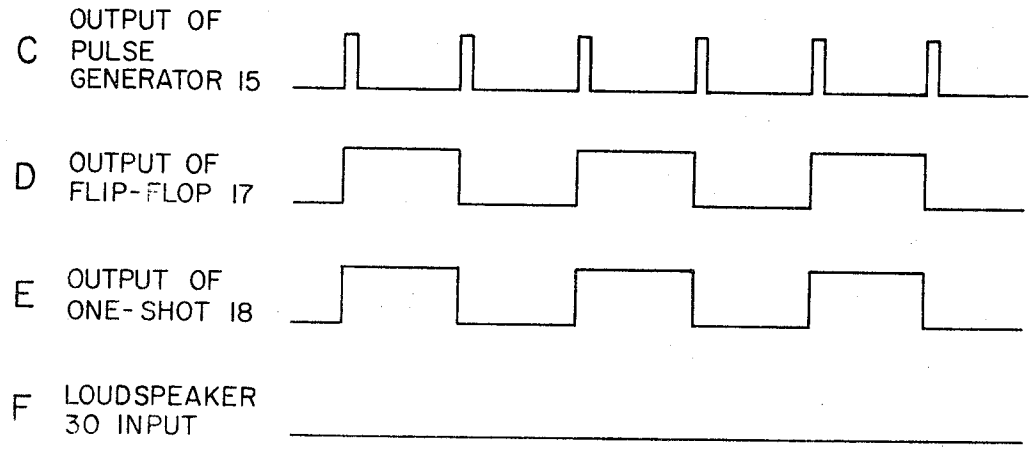


FIG. 3

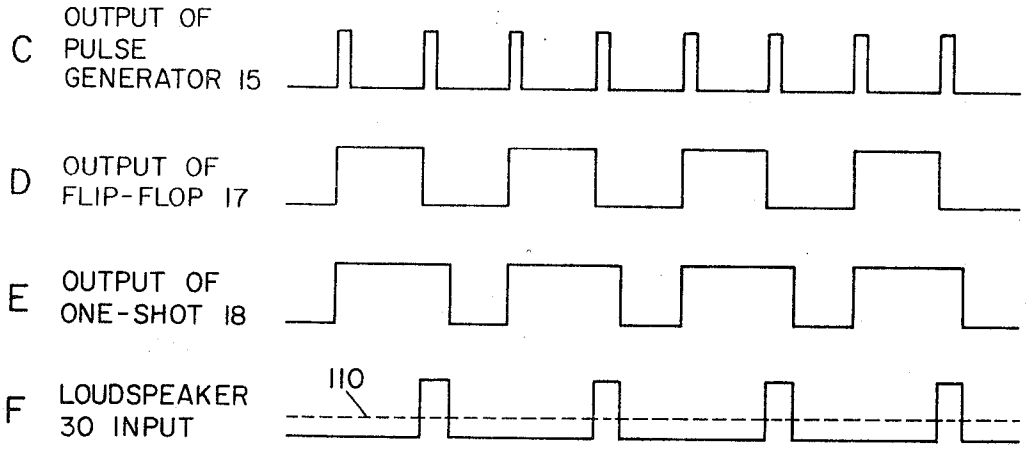


FIG. 4

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AUDIBLE BLOOD PRESSURE MONITOR

BACKGROUND OF THE INVENTION

This invention relates to means for monitoring blood pressure and heart beat and more particularly to such a monitor which will generate an audible signal containing information both as to blood pressure and heart beat rate and which will automatically provide an alarm signal should heart beat become arrhythmic or cease.

The usual method of monitoring arterial and venous blood pressure during surgery involves the cannulation of the patient's arteries and veins. These cannula are attached to strain gauges comprising the interface with electronic circuits that display the pressure on an oscilloscope as a vertical displacement of the oscilloscope trace from a base line. This displacement is calibrated in millimeters of mercury pressure. Patient heart beats, which produce momentary blood pressure spikes, are displayed as spikes on the oscilloscope trace. It is difficult, if not impossible, for the operating surgeon to monitor the oscilloscope directly since he must be concerned with the operation, itself. It is also impractical for personnel in the operating room to monitor the oscilloscope since it is an extremely boring job, especially when all parameters appear to be normal. It has been found by experience that the oscilloscope cannot be monitored continuously by operating room personnel regardless of skill or assignment without their attention being diverted to other problems within the operating room.

Conventional electrocardiographic apparatus has also been used to monitor heart action with the electrocardiographic apparatus being connected to an oscilloscope to visually display both heart beat rate and blood pressure or connected to audio apparatus for generating an audible signal containing information only as to heart beat rate.

SUMMARY OF THE INVENTION

Means for providing an audio signal which contains information both as to blood pressure and heart beat could be advantageously employed to monitor the cardiac condition of a patent. It would also be advantageous if the aforementioned audible signal is muted whenever the heart action is normal so as not to distract operating personnel. It would also be advantageous to provide means which would sound alarm whenever an arrhythmia developes.

The aforementioned advantages are provided by the present invention. The invention herein resides in electronic circuitry which is interfaced with a patient by some sort of telemetering device which generates an electrical signal whose magnitude is proportional to blood pressure. As aforementioned, this telemetering device can be a strain gauge attached to a cannula which is inserted into the patient's artery or vein, depending on whether the patient's arterial or venous pressure is to be monitored. The electrical signal generated by the strain gauge will follow the blood pressure. For example, in a person with a blood pressure of 120 systolic over 80 diastolic the pressure before the heart contracts would be 80 millimeters of mercury and would be raised by contraction of the heart to 120 millimeters of mercury and at the cessation of the heart beat the pressure would slowly fall back to 80 millimeters of mercury to be repeated periodically at the heart beat rate. The voltage level output of a strain gauge telemetering device will track the blood pressure approximately linearly. The strain gauge output controls the repetition rate of a pulse generator to thus generate a first pulse train whose pulse repetition frequency is proportional to blood pressure. The frequency form the pulse generator is then divided by 2 yielding a square wave of 50 percent duty cycle if the blood pressure, that is the output of the strain gauge, remains constant. The square wave triggers a one-shot having a pulsewidth which is settable by a calibrated knob. For a selected normal value of blood pressure the pulsewidth can be made equal to that of the square wave so that if subtracted, the two signals cancel. If the pulse generator frequency should change, indicating that blood pressure has changed, the pulsewidth of the square wave changes but the monostable output pulsewidth remains the same. Thus, by subtracting the one-shot pulse from the square wave, an output results which is comprised of a train of pulses of a frequency equal to that of the square wave and having a width proportional to the change in blood pressure from the normal set value. The resultant pulse train is fed to a loudspeaker where the resultant pitch of the sound indicates blood pressure and the strength of the sound is proportional to the deviation of the blood pressure from the normal setting. This is so because the power contained in a pulse train is proportional to the width of the pulses which, as has been mentioned, is related to the deviation of the blood pressure from a set normal value.

Of course, as the heart beats the blood pressure will vary over its normal systolic and diastolic range. This will be evidenced by the electronic circuitry by its production of an audible signal whose pitch and intensity will both increase as the heart contracts and whose pitch and intensity will decrease as the heart relaxes. Since both change of pitch and changes of sound intensity can be used to indicate heart beat a muting circuit is provided which suppresses the changes in sound intensity so long as the blood pressure remains within acceptable limits, so that the sound level is kept low even if the patient's blood pressure drifts up and down within certain limits while the change in sound pitch is monitored to provide an indication of heart beat rate.

An alarm circuit is also provided which sounds an alarm if heart beat should cease or the heart become arrhythmic. This is accomplished by the use of a discharge circuit which is charged by the voltage spikes output from the strain gauge caused by the contraction of the heart as it beats. This voltage enables a gate through which the pulse train whose pulse repetition frequency is proportional to blood pressure is fed to the subtraction circuit. If the heart beat ceases or the heart becomes arrhythmic the voltage spikes generated by the strain gauge in response to the contractions of the heart are no longer present and the voltage across the discharge circuit will discharge and disable the aforementioned gate. The subtraction circuit now only has an input from the one-shot and thus will generate an output having the highest possible energy content. A resultant high audio level monotone audible signal which decays as blood pressure drops comprises the alarm.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the invention.

FIGS. 2A and 2B together comprise a schematic of the invention.

FIG. 3 shows the pulse train waveforms at various points in the circuitry of the invention when the monitor has been normalized to generate a minimum audible output signal.

FIG. 4 shows the pulse train voltage waves at various points in the circuitry of the invention when blood pressure has deviated from the normal.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1, a block diagram of the invention, there is seen a transducer 10, suitably a strain gauge, which interfaces with the blood stream of a patient and generates a voltage output proportional to blood pressure at input terminal 12 of the blood pressure monitor. The signal on input terminal 12 is applied to signal conditioner 14, which is basically an amplifier with variable sensitivity to accept a wide range of input voltages. Signal conditioner output is a DC voltage level proportional to input voltage and is applied to pulse generator 15 which in response thereto generates a train of pulses whose pulse repetition frequency is proportional to its input voltage. This pulse train is applied to a divide by 2 multivibrator, suitably flip-flop 17, connected as a binary divider. The output of flip-flop 17 is a square wave having a duty cycle of 50 percent so long as blood pressure remains constant. Should the blood pressure change, for example increase, the voltage input to signal conditioner 14 also increases, thus in-

creasing the pulse repetition frequency for the pulse train applied to flip-flop **17** so that the frequency of the square wave output from flip-flop **17** increases and its pulse width decreases. Flip-flop **17** output pulse train is applied to one-shot **18** which is triggered on by the leading edge of the pulses. The width of the one-shot output pulse is variable, for reasons which will be made obvious later, by manipulation of a control knob **19** which adjusts means not shown here but which will be shown below. The output pulses from one-shot **18** are applied to exclusive Or gate **20**.

The output signal from signal conditioner **14** is also applied to alarm circuit **21** which includes a discharge circuit which is charged by the rapid variations in the signal conditioner output signal which are characteristically present while the heart is beating. So long as the discharge circuit is being charged the alarm circuit generates an output along line **22** to And gate **25** thereby qualifying this latter gate. The output pulse train from flip-flop **17** is applied along line **23** to And gate **25** which, when qualified, passes this pulse train to exclusive Or gate **20**. Thus, so long as the heart is beating exclusive Or gate **20** receives as inputs the pulse train from one-shot **18** and the pulse train from flip-flop **17**. Exclusive Or gate **20** will pass a signal therethrough when only one of its input terminals is energized and will pass no signal therethrough when both or neither of the input terminals are energized. Exclusive Or gate **20** thus operates as a subtraction circuit to subtract the pulse train generated by one-shot **18** from the pulse train generated by flip-flop **17**. If, at some normal valve of blood pressure, the output pulse from one-shot **18** is made equal in length to the pulse generated by flip-flop **17**, exclusive Or gate **20** will pass no signal therethrough. However, if the heart is beating, it is known that the blood pressure will vary during each heart between its systolic and diastolic pressures so that there is generally some output from exclusive Or gate **20** whose energy content is indicative of heart beat rate. Additionally, since the output pulse train of pulse generator **15** is a pulse repetition frequency which is related to blood pressure, the pulse repetition frequency of the signal output of exclusive Or gate **20** will vary in accordance with the heart beat. A muting circuit **27** widens the range over which the output from exclusive Or gate **20** is suppressed. The width of this range is normally set by a potentiometer as will be later shown. With this potentiometer set to zero, the output from the exclusive Or gate is zero only when the input pulses thereto are exactly the same width. Since the exclusive Or gate output pulsewidth gradually increases with increasing difference between the input pulses, the power contained in the output also gradually increases. The effect is that the resultant null notch has sides where a gradual increase in signal is obtained as the frequency of the pulses deviates from the point where their pulsewidths are equal. This in itself provides a muting in the immediate vicinity of the null point, but the range is rather narrow. If it is desired to keep the signal level low until certain blood pressure limits are reached, the potentiometer can be varied to give up to 100 percent muting range. The signal from the muting circuit **27** is applied to loudspeaker **30** through amplifier **28** so as to generate an audible signal whose intensity is related to the deviation of blood pressure from a preset normal value and whose change in pitch is indicative of heart beat.

As previously mentioned, alarm circuit **21** includes a discharge circuit which is charged by the rapid variations in the output signal from signal conditioner **14** which are produced by the rapid fluctuations in blood pressure characteristic of the heart beat. Should the heart cease to beat or become arrhythmic these rapid signal variations will cease and the discharge circuit will discharge and remove the signal from line **22**, thus closing gate **25**. The output pulse train from flip-flop **17** will thus be blocked by gate **25** and only the pulse train from one-shot **18** will be applied to exclusive Or gate **20**. This latter pulse train will thus pass directly therethrough so as to cause loudspeaker **30** to generate a continuous high level monotone audible signal which slowly decays as blood pressure drops.

Referring now to FIG. **2A** the blood pressure signals generated by the pressure transducer are applied to input terminal **12** of the blood pressure monitor. These signals are applied across resistor **40** and applied via adjustable resistor slider **40*a*** to the gate electrode of field effect transistor **41**. The adjustment of slider **40a** permits the monitor to accept a wide range of input signal voltages. Resistor **40** is chosen to be a large value and this fact, together with the use of field effect transistor **41** results in the input terminal **12** having a high input impedance thus preventing loading of the transducer. Transistors **41** and **42** are differentially connected and together comprise an amplifier with the amplifier output being taken from the collector electrode of transistor **42**. Transistor **42** receives an adjustable bias at its base electrode from the voltage divider comprised of resistor **44** and potentiometer **45** serially connected between a source of A+ voltage and ground. By the manipulation of potentiometer **45** the bias at the base electrode of transistor **42** may be varied so as to change the amplifier output voltage level at the collector of transistor **42**. Filter capacitor **46** removes high frequencies from the amplifier output so as to reduce noise and interference. The output from the signal conditioner **14** is applied to the time constant circuit comprised of resistor **47** and capacitor **48** in the pulse generator **15**. Unijunction transistor **50**, together with resistor **47** and capacitor **48** comprise a pulse generator with the unijunction becoming conductive to discharge capacitor **48** whenever the voltage thereacross reaches the unijunction trigger level. The resultant pulse appears across the voltage divider comprised of resistors **51** and **52** and is coupled via resistor **51** and capacitor **53** in parallel to the toggle input C of flip-flop **17**. This latter circuit element is well known to those skilled in the art and its schematic need not be shown for a complete understanding of the invention. Each output pulse from pulse generator **15** causes flip-flop **17** to complement so that its output is comprised of a pulse train having an approximately 50 percent duty cycle.

The flip-flop output pulse train is applied to the one-shot comprised of transistors **60** and **65** through capacitor **55** and diode **56** so that the one-shot is triggered on positive voltage excursions. The one-shot output pulsewidth, which is determined by the resistance of potentiometer **63** and resistor **62** and capacitor **61**, can be varied by the adjustment of potentiometer **63** which is coupled to knob **19** seen in FIG. 1. The one-shot output pulse train appears at terminal E while the flip-flop output pulse train appears at terminal D.

The output of signal conditioner **14** is also applied to the alarm circuit **21** at the gate electrode of field effect transistor **70**. The use of a field effect transistor at this point presents a high impedance to the output of the signal conditioner thus preventing excessive loading of that circuit. The amplified output of transistor **70** is picked off resistor **71** by resistor slider **71*a*** and capacitively coupled through capacitor **73** to the base electrode of transistor **78**. This latter transistor receives a DC bias from the voltage divider comprised of resistors **75** and **76** connected across the A+ voltage supply. Output is taken from the collector of transistor **78** and capacitively coupled to the diode circuit comprised of diodes **80'** and **81'** at the base of transistor **85'**. Capacitor **72** eliminates electrical noise which may be present on slider **71*a*** while capacitors **73** and **79** insure that only rapid variations in blood pressure characteristic of a heart beat are effective at the base of transistor **85'** so as to hold that transistor non-conductive so that its collector electrode and hence terminal G are disconnected from ground. However, should the heart stop or become arrhythmic, rapid variations in blood pressure are no longer present, thus the negative charge across capacitor **84'** will leak off through resistor **83'** until transistor **85'** becomes conductive,at which time terminal G will be grounded.

Referring now to FIG. **2B**, wherein exclusive Or gate **20** and And gate **25** are seen to be comprised of transistors **80, 81, 83** and **85** and diodes **82** and **84**. The operation of these gates is such as to provide a current sink at the input of muting circuit **27** whenever the gates are open. The pulse train from one-shot

18 is applied to terminal E and hence to the base electrode of transistor 80 while the pulse train of flip-flop 17 is applied to terminal D and hence to the base of transistor 85. With signal present on both terminals E and D, transistors 80 and 85 are both conductive so that their respective collector electrodes are grounded, thus grounding the base electrodes of transistors 81 and 83 holding these latter transistors non-conductive and hence no current can flow therethrough, thus presenting a closed gate condition to muting circuit 27. With the signal present on either terminal E or terminalD, but not both, for example, with a signal on terminal E and no signal on terminal D transistor 80 is conductive while transistor 85 is non-conductive, thus grounding the collector electrode of transistor 80. Transistor 81 is thus non-conductive, however, transistor 83 is conductive and current can flow therethrough and trough diode 84 and transistor 80 to ground, thus indicating the gate open condition to muting circuit 27. Of course, since the circuit is symmetrical, the presence of a signal at terminal D and the absence of a signal at terminal E accomplishes the same gate open condition.

It will be remembered that in the absence of a heart beat or in the presence of an arrhythmic heart condition, terminal G is grounded thus grounding the base electrode of transistor 81'. This effectively eliminates any signal at terminal E from effecting the gating circuit. Thus, the pulse train from flip-flop 17 appearing on terminal D will be fully effective to open the gating circuit so as to present a current sink to muting circuit 27.

As the width of the pulses from the exclusive Or gate 20 goes up, the DC level of the pulse train goes up. It will be remembered that the output of the exclusive Or gate is zero only when the pulse train from flip-flop 17 and one-shot 18 are identical and that this occurs only at some normal present value of blood pressure but that this normal preset value of blood pressure occurs only momentarily during each heart beat. It will also be remembered that the pulse train passed by the exclusive Or gate contains redundant information as to heart beat in that this latter pulse train includes the heart beat information in both its DC level and its pulse repetition frequency. Muting circuit 27 is provided to increase the width of the null in which the pulse train from the exclusive Or gate is muted. Muting circuit 27 is comprised of the amplifier transistors 90 and 92, to the base electrodes of which the output from the exclusive Or gate is applied, a comparator in the form of a differential amplifier comprised of transistors 96 and 97, and a switching transistor 93. The null width over which the pulse train from the exclusive Or gate is muted is determined by the setting of potentiometer 99, which sets the bias on the base electrode of transistor 97, which comprises the threshold level of the comparator comprised of transistors 96 and 97. As already mentioned, the output from the exclusive Or gate is applied to the base electrode of transistor 92 wherein it is amplified and applied through the integrating circuit comprised of resistor 87 and capacitor 88 to the base electrode of transistor 96. The integrating circuit converts the amplified pulse train to a DC voltage level. So long as the DC level of the amplified pulse train remains below the comparator threshold level set by potentiometer 99 switch transistor 93 will be conductive and will prevent the pulse train from passing directly from amplifier transistor 90, resistor 95 and diode 94 to amplifier 28. During the time switching transistor 93 is conductive a portion of the signal from amplifier transistor 99 is shunted to amplifier 28 and loudspeaker 30 through capacitor 91 so as to provide some background but muted audible signal indicative of the heart beat rate from loudspeaker 30. When the DC level of the amplified pulse train at the base electrode of transistor 96 exceeds the threshold value for the comparator, transistor 96 will turn on and transistor 97 will turn off, thus causing switching transistor 93 to become non-conductive. The signal from amplifier transistor 90 now passes directly through resistor 95 and diode 94 to the amplifier 28. Amplifier 28 is comprised of output transistor 100, diode 102 which protects the output transistor from inductive overshoots generated by the loudspeaker when pulse driven and a volume adjusting potentiometer 103 connected across diode 102, that is, between the collector electrode of transistor 100 and ground. The signal tapped from potentiometer 103 drives loudspeaker 30.

Referring now also to FIG. 3 wherein the letters C, D, E and F correspond to like indicated points in the circuitry of FIGS. 2A and 2B, it can be seen that the output of pulse generator 15 is comprised of a series of narrow pulses. The output pulse train of flip-flop 17, as seen at point D, is comprised of a series of pulses having approximately 50 percent duty cycle and whose leading edge coincides with the leading edge of the pulses at point C since flip-flop 17 is triggered by positive-going pulses, while the pulse train at point E is similarly synchronized with the pulse trains at points C and D, since the one-shot is triggered by the positive-going pulses at point D. It can further be seen that the pulse train at point E have been adjusted by potentiometer 63 to be identical to the pulse train at point D. The energy content of the loudspeaker 30 input at point F is thus zero.

Referring now to FIG. 4 wherein there is seen the waveforms of FIG. 3 after the blood pressure has increased somewhat from its normal preset condition. It will be remembered that if blood pressure rises the pulse repetition frequency of the pulse train from pulse generator 15 will increase as can be seen by comparing line C of FIG. 4 with line C of FIG. 3. The pulse train output of flip-flop 17 as seen at line D will thus be comprised of shorter width pulses having a higher pulse repetition frequency. Of course, the pulse train generated by one-shot 18 would be comprised of pulses having the same width as in FIG. 3, but having the same pulse repetition frequency as the pulse train at point D. Thus the pulse train at point E will have a duty cycle in excess of 50 percent. Subtraction of the pulse trains on lines D and E from one another results in the pulse train at line F, which is the pulse train applied to the loudspeaker 30 to generate the audible signal when the DC level of the waveform on line F is above the threshold set by potentiometer 99 in FIG. 2B. If the DC level of the waveform on line F is below the threshold set by potentiometer 99 that part of the pulses above line 110 will be suppressed in that only that portion of the pulses below line 110 will be able to proceed from amplifier transistor 90 to point F through capacitor 91 since switching transistor 93 will be conductive thus suppressing the pulse path through resistor 95 and diode 94.

The invention claimed is:

1. A blood pressure monitor comprising:
means for generating a first pulse train having a pulse repetition frequency proportional to blood pressure and a duty cycle related to the rate of blood pressure change;
adjustable means responsive to said first pulse train for generating a second pulse train having a pulse repetition frequency equal to the pulse repetition frequency of said first pulse train and synchronized therewith and including means for adjusting the pulsewidth of the pulses in said second pulse train, said second train pulsewidth thereafter remaining constant;
means combining said first and second pulse trains for generating an output signal; and,
utilizations means responsive to said output signal for monitoring said blood pressure.

2. A blood pressure monitor as recited in claim 1 with additionally muting means for attenuating said output signal when said output signal is below a predetermined threshold.

3. A blood pressure monitor as recited in claim 2 wherein said muting means includes means for varying said predetermined threshold.

4. A blood pressure monitor as recited in claim 1 wherein said combining means comprises means for subtracting one of said first and second pulse trains from the other of said pulse trains to produce a third pulse train comprising said output signal.

5. A blood pressure monitor as recited in claim 4 with additionally:

means integrating said third pulse train for generating a DC voltage;

threshold means responsible to said DC voltage for generating a switching signal;

a first attenuated signal path connecting said subtracting means with said utilization means; and,

a second signal path controlled by said switching signal and shunting said first path.

6. A blood pressure monitor as recited in claim 4 with additionally:

means integrating said third pulse train for generating a DC voltage; and,

means responsive to said DC voltage for varying the response of said utilization means to said third pulse train.

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