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REPLY TO
ATTN OF: GP

TO: KSI/Scientific & Technical Information Division
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,850,169

Government or Corporate Employee : U.S. Government

Supplementary Corporate Source (if applicable) : [Handwritten scribble]

NASA Patent Case No. : LEW-11,581-1

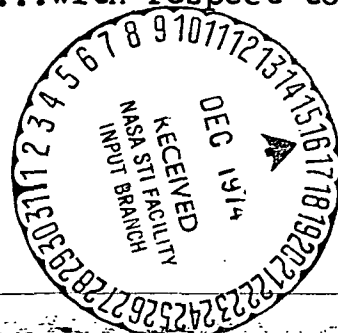
NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES NO

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

Bonnie L. Woerner

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Enclosure



(NASA-Case-LEW-11581-1) CIRCUIT FOR
 DETECTING INITIAL SYSTOLE AND DICROTIC
 NOTCH Patent (NASA) 7 P CSCI 06B
 00/54 03999
 Unclas

[54] **CIRCUIT FOR DETECTING INITIAL SYSTOLE AND DICROTIC NOTCH**

3,498,292 3/1970 Jorgensen et al. 128/2.06 R
3,646,931 3/1972 Phelps et al. 128/2.05 P

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[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, D.C.

[57] **ABSTRACT**

[22] Filed: **Jan. 30, 1973**

Circuitry is disclosed for processing an arterial pressure waveform to produce during any one cycle a pulse corresponding to the initial systole and a pulse corresponding to the dicrotic notch.

[21] Appl. No.: **327,921**

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

In a first channel, an electrical analog of the arterial pressure waveform is filtered and then compared to the original waveform to produce an initial systole signal. In a second channel, the analog is differentiated, filtered and fed through a gate controlled by pulses from the first channel to produce an electrical pulse corresponding to the dicrotic notch.

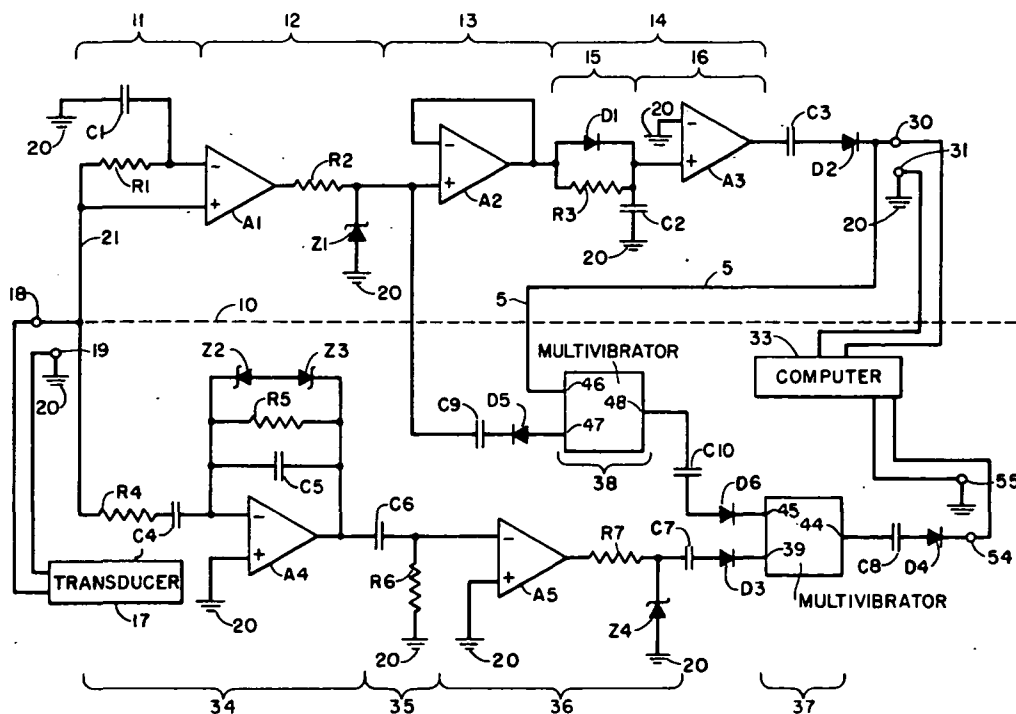
[51] Int. Cl. **A61b 5/02**

[58] **Field of Search**.... 128/2.05 A, 2.05 M, 2.05 P, 128/2.05 Q, 2.05 R, 2.05 S, 2.05 T, 2.05 U, 2.06 R

[56] **References Cited**
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11 Claims, 2 Drawing Figures



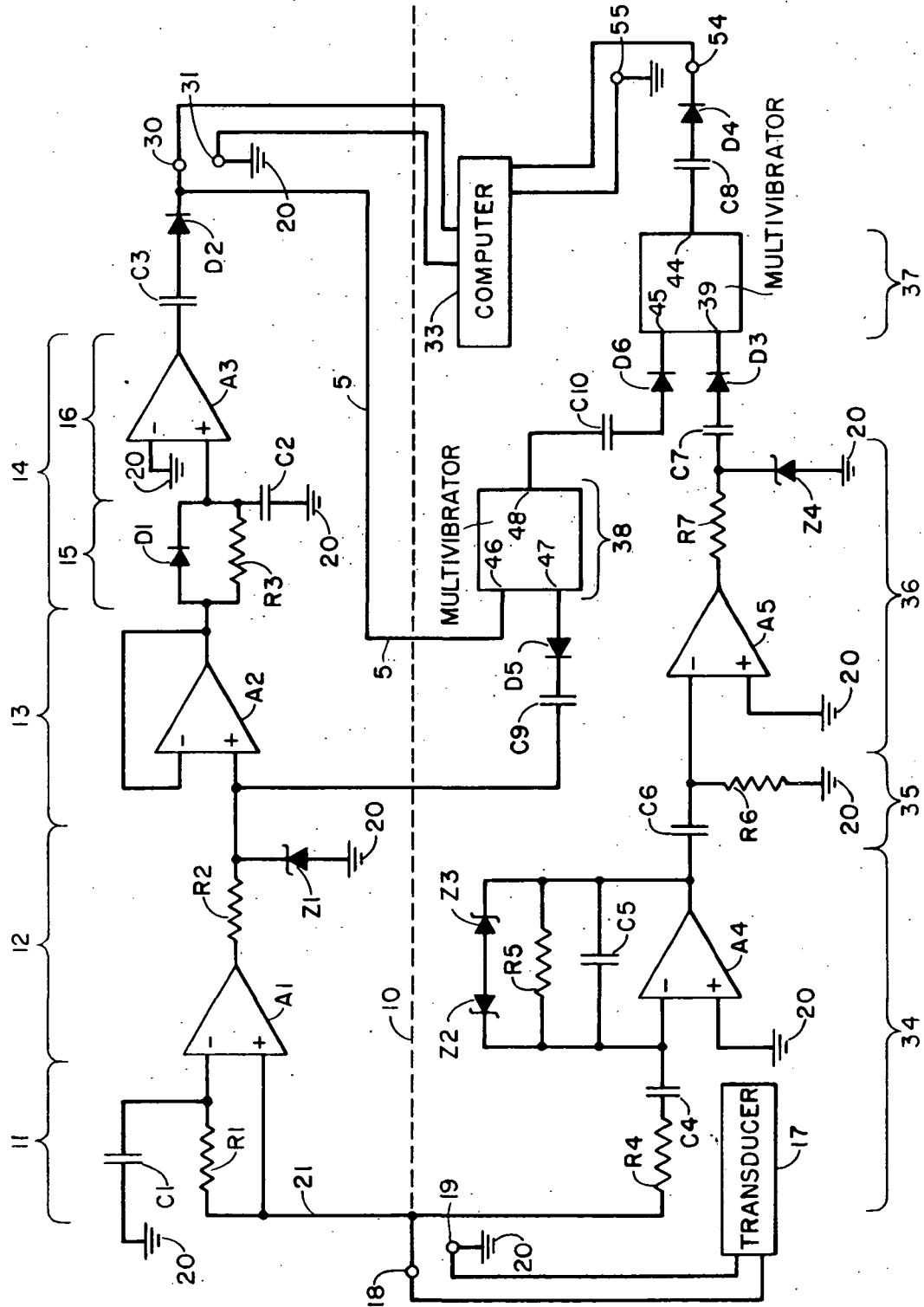


FIG. 1

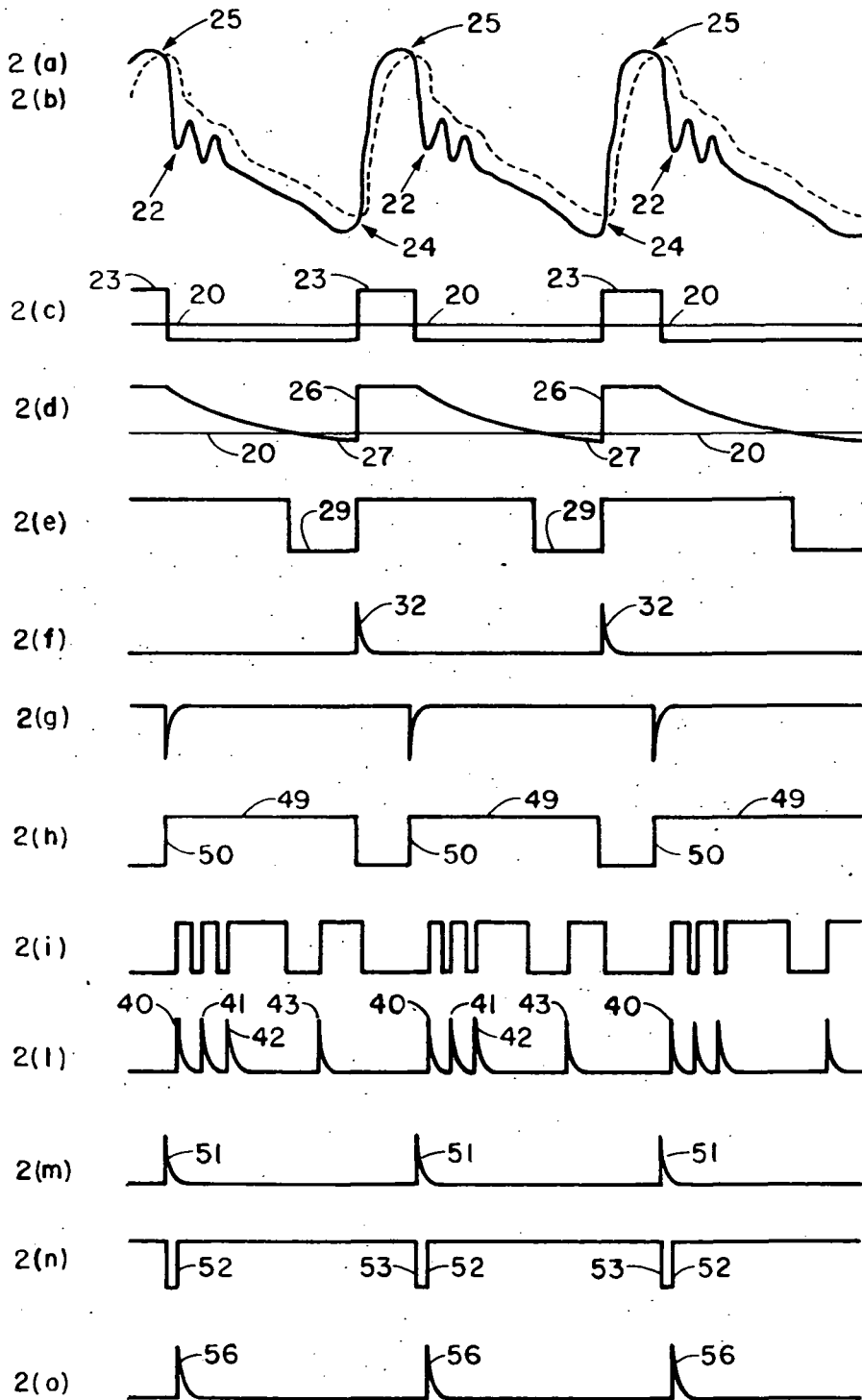


Fig. 2

CIRCUIT FOR DETECTING INITIAL SYSTOLE AND DICROTIC NOTCH

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to electronic processing circuits and is directed more particularly to circuitry for processing an arterial pressure waveform to produce one discrete electrical signal that coincides with the initial systole and another signal which coincides with the dicrotic notch. Initial systole is defined herein as the point in time at which the aortic blood pressure rapidly increases as a result of the heart pumping blood into the aortic artery. The dicrotic notch is the pressure disturbance caused by the closure of the aortic valve.

In studying and treating patients having heart damage and heart disease, the rise and fall of blood pressure in arteries near the heart is an important parameter to be observed. Transducers are available which convert the arterial pressure waveform into an electric signal which may be displayed on devices such as oscilloscopes or recorders. However, where automatic monitoring of the arterial pressure is desired, as for example to provide a signal when the arterial pressure waveform deviates from a prescribed pattern, computers are being utilized. Such computers require timing signals corresponding to the initial systole and dicrotic notch of each cycle of heart operation. Such apparatus must be operative over a range of heartbeat rates between 50 and 200 beats per minute and must operate reliably for a variety of waveforms that can result from abnormal circulatory dynamics, from irregular heartbeats or from breathing pressures. Detecting changes in slope of the arterial pressure waveforms is not a satisfactory approach because extraneous oscillations are also detected. The approach of using a signal which is initiated when the arterial pressure exceeds its average value has the disadvantages of producing late signals and false signals when the pressure wave oscillates through the average value.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the invention to provide a new and novel initial systole and dicrotic notch detecting circuit.

It is another object of the invention to provide an initial systole and dicrotic notch detecting circuit which is relatively simple and inexpensive.

An additional object of the invention is to provide an initial systole and dicrotic notch detector circuit which is not adversely effected by abnormal circulatory dynamics, irregular heart beats, or breathing pressures.

Still another object of the invention is to provide an initial systole and dicrotic notch detector circuit which operates over a range of 50 to 200 heartbeats per minute.

Yet another object of the invention is to provide circuitry including means for filtering an arterial pressure voltage signal and comparing the filtered signal to the original signal to detect initial systole even in the presence of low frequency breathing disturbances.

Still another object of the invention is to provide circuitry that produces a discrete output signal each time that the low frequency portion of the arterial pressure signal has a positive inflection during the period that begins the first time the pressure signal after initial systole becomes less in magnitude than its filtered waveform.

A further object of the invention is to provide initial systole and dicrotic notch detecting circuitry which includes pulse width discrimination circuitry to suppress effects of detrimental high frequency disturbances.

In summary, the circuitry of the invention filters the arterial pressure waveform to remove low frequency components and then compares this filtered waveform to the original waveform to produce a rectangular pulse whenever the original waveform is greater in magnitude than the filtered waveform. These pulses are passed through a unidirectional low pass filter and a comparator and then through a unidirectional coupling circuit, the output of which is a discrete voltage pulse corresponding to the initial systole. The arterial pressure waveform is also passed through a differentiator, and a first order high pass filter to produce a signal that is related to the second derivative of the arterial pressure waveform. This signal is passed through a comparator and to a multivibrator. The multivibrator is provided with reset signals from a second multivibrator which is reset by the discrete systole pulses and set by the square pulses. The first multivibrator does not produce an output except for preselected ones of the pulses applied to the set input. The output of the first multivibrator is fed through a unidirectional coupling circuit whose output is a discrete pulse corresponding to the dicrotic notch.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a circuit for detecting the initial systole and the dicrotic notch.

FIG. 2 is an illustration of the various voltage wave-shapes found at various points throughout the circuit of FIG. 1.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring first to FIG. 2, the pulses shown at 2(f) and 2(o) are the desired outputs of the circuit of FIG. 1 and correspond respectfully to the initial systole and dicrotic notch.

Referring now to FIG. 1, the circuitry above dashed line 10 provides an initial systole detection channel while the circuitry below line 10 provides a dicrotic notch detection channel. The systole channel comprises generally a signal processing circuit 11, a comparator circuit 12, an impedance matching circuit 13 and a pulse width discriminator 14 which may include a unidirectional low pass filter 15 and a comparator 16. An electrical signal corresponding to an arterial pressure waveform as illustrated by waveshape 2(a) is supplied from a transducer 17 to an input means such as terminals 18 and 19.

Terminal 19 is connected to a circuit common point as at 20 while terminal 18 is connected through a lead 21 to a positive input of an operational amplifier A1 and also through a resistor R1 to a negative input of the operational amplifier A1. The negative input of the operational amplifier A1 is also connected through a capacitor C1 to circuit common 20.

Resistor R1 and capacitor C1 comprise a low pass filter circuit which removes the oscillations 22 of waveshape 2(a) which begin at the dicrotic notch so that the waveshape applied to the negative input of the operational amplifier A1 is that indicated by the dashed waveshape. However, the principal purpose of the low pass filter is to cause waveshape 2(b) to lag waveshape 2(a) to provide cross-over points 24 and 25 which establish the leading and trailing edges of pulses 23 and shown in FIG. 2(c).

The output of amplifier A1 is directed through a resistor R2 to a positive input of an operational amplifier A2, a zener diode Z1 being connected between the positive input of amplifier A2 and circuit common 20. The voltage waveshape applied to the positive input of amplifier A2 is shown at 2(c) and includes square pulses 23 having leading edges corresponding in time to the points at which waveshape 2(a) becomes greater than waveshape 2(b) as indicated at points 24 and also having trailing edges corresponding in time to the points at which waveshape 2(a) again becomes less than waveshape 2(b) as indicated at points 25.

The low pass filter comprising R1, C1 has no significant effect on breathing frequency components which may be included in the arterial pressure wave. Therefore, breathing frequency components are present equally at both inputs of amplifier A1. Because the input of amplifier A1 is differential and provides an output when waveshape 2(a) minus waveshape 2(b) is positive, the breathing frequency components cancel each other. Thus the output of comparator 12 contains no breathing frequency components which might adversely affect the time of occurrence of the desired output initial systole pulse.

The output of amplifier A2 is connected to the unidirectional low pass filter 15 and is also connected back to its own negative input to provide a follower circuit which isolates filter 15 from the comparator circuit 12. Filter circuit 15 comprises a resistor R3 connected in parallel with a diode D1 between the output of amplifier A2 and one side of a capacitor C2, the other side of which is connected to circuit common 20. Diode D1, resistor R3 and capacitor C2 are connected to the positive input of an amplifier A3 which has its negative input connected to circuit common 20. The voltage waveshape appearing at the positive input of the amplifier A3 is shown at 2(d). The leading edges of pulses 26 correspond to the leading edges of pulses 23 which are passed by the diode D1. However, the negative going trailing edges of pulses 23 are blocked by diode D1 causing the trailing edges of pulses 26 to decay exponentially. Portions 27 of a pulse 26 which fall below circuit common reference level 20 cause the output of amplifier A3 to go negative as indicated at 29 in waveshape 2(e).

The output of amplifier A3 is directed through a capacitor C3 and the diode D2 to a terminal 30 of an initial systole output means which may also include a circuit common terminal 31. The capacitor C3 and the diode D2 comprise a unidirectional coupling circuit which passes only the positive going portions of waveshape 2(e) so that the signal appearing at initial systole output terminal 30 relative to 31 comprises pulses 32 each of which corresponds to the initial systole as shown by waveshape 2(a). Output terminals 30 and 31 may be connected to a suitable computer 33 to provide an initial systole timing signal thereto.

In order to produce a pulse corresponding to the dicrotic notch of an arterial pressure waveform, the dicrotic notch detecting channel may comprise generally a low frequency differentiator circuit 34, a first order, high pass filter 35, a comparator 36, and multivibrators 37 and 38 which serve as gate means. The purpose of the differentiator circuit 34 and the filter circuit 35 is to produce for the comparator 36 a waveshape which is essentially a second derivative with respect to time of waveshape 2(a).

Differentiator 34 comprises an amplifier A4 having a positive input connected to circuit common 20 and a negative input connected to a capacitor C4 and a resistor R4 to the input signal terminal 18. A resistor R5 and a capacitor C5 are connected in parallel relationship between the negative input of amplifier A4 and its output to provide feedback. To prevent latch-up of amplifier A4, a pair of zener diodes Z2 and Z3 may be connected in back to back relationship between the output and the negative input of amplifier A4.

The filter 35 may be comprised of a capacitor C6 connected between the output of amplifier A4 and a negative input of an operational amplifier A5, a point between C6 and the negative input of amplifier A5 being connected to circuit common 20 through a resistor R6.

The comparator circuit 36 processes the second derivative of waveshape 2(a) which, as indicated previously, is applied to the negative terminal of amplifier A5, to produce a waveshape as shown at 2(i). The comparator 36 includes the amplifier A5, a resistor R7 connected between the output of amplifier A5 and one side of a capacitor C7 and a zener diode Z4 connected as shown from a point between R7 and C7 to circuit common as at 20. The positive input of an amplifier A5 connected to circuit common 20 completes the comparator circuit 36.

The other side of capacitor C7 is connected through a diode D3 to a set input of multivibrator 37 which serves as a gate means. The waveshape applied to set input 39 is shown at 2(1) and comprises pulses which correspond to the positive going portions of the output 2(i) of the comparator circuit 36. The negative going portions of waveshape 2(i) are, of course, blocked by the diode D3.

It will be seen that the waveshape 2(1) includes closely spaced pulses, 40, 41 and 42 and remotely spaced pulse 43. Each of these pulses results from some positive inflection in the arterial pressure wave 2(a). Accordingly, all the pulses except those corresponding to the dicrotic notch must be eliminated to obtain a waveshape as shown at 2(n) at an output 44 of the multivibrator 37. To this end, there is provided a multivibrator 38 providing a reset input 46 connected via a lead 5 to output terminal 30 and a set input 47 connected through a diode D5 and a capacitor C9 to output of comparator 12 which is also the positive input side of A2. An output 48 of multivibrator 38 is connected through a capacitor C10 and a diode D6 to a reset input 45 of multivibrator 37. Multivibrator 38 together with lead 5 and the coupling circuits comprised of C9, D5 and C10, D6 form a means for resetting gate means 37.

According to the interconnections of multivibrator 38 as just described, the waveshape 2(f) is applied to input 46 to reset multivibrator 38. Multivibrator 38 is then set when input 47 receives a waveshape 2(g)

which results from the passage of waveshape 2(c), the output of discriminator 12, through capacitor C9 and diode D5. The resultant output waveshape produced at output 48 of the multivibrator 38 is shown at 2(h) and is made up of pulses 49.

Only the positive going fronts 50 of pulses 49 are passed by capacitor C10 and diode D6 so that the resultant waveshape applied to the reset input 45 of multivibrator 37 is made up of pulses 51 as illustrated by waveshape 2(m). Thus it will be seen that each pulse 51 of waveshape 2(m) resets multivibrator 37 and each pulse 40 of waveshape 2(1) sets multivibrator 37 so that pulses 41, 42 and 43 produce no output at 44 of multivibrator 37. The output waveshape at output 44 of multivibrator 37 is shown at 2(n) and includes positive going wavefronts 52 corresponding to the set pulses 40 and negative going portions corresponding to the reset pulses 51.

The output 44 of multivibrator 37 is connected to a capacitor C8 and a diode D4 to an output terminal 54 which with a circuit common terminal 55 comprises a dicrotic notch output signal means. Terminals 54 and 55 are connected to the computer 33. The diode D4 blocks the negative going portions 53 of waveshape 2(n) thereby producing at the terminal 54 relative to 55, pulses 56 as shown by waveshape 2(o) of FIG. 2.

From the foregoing, it will be seen that the circuitry of FIG. 1 produces at output terminal 30 relative to 31, a waveform 2(f) made up of pulses 32 which corresponds to the initial systole. Similarly, at the output terminal 54 relative to 55 there appears a waveshape 2(o) made up of pulses 56, each of which corresponds to a dicrotic notch in the arterial pressure waveform. The initial systole output pulses and the dicrotic notch output pulses are the desired discrete timing signals to be generated by the circuitry embodying the invention and may be used or directed to computers or other electronic equipment for studying the heart.

What is claimed is:

1. Circuitry for producing from a transducer generated electrical analog of an arterial pressure waveform an initial systole spike and a dicrotic notch spike, said circuitry comprising:

low pass filter circuit means;

a first comparator having a first input adapted to be connected to said transducer and a second input adapted to be connected to said transducer through said low pass filter circuit means;

a second comparator having input means and output means;

unidirectional low pass filter circuit means;

means for connecting said unidirectional low pass filter means between an output of said first comparator and said input means of said second comparator;

first unidirectional coupling means having one end connected to said output means of said second comparator to provide discrete initial systole pulses at its other end;

a differentiator circuit having input means and output means;

a third comparator having input means and output means;

a high pass filter connected between said output means of said differentiator and said input means of said third comparator;

means for connecting said input means of said differentiator to said transducer;

gate means having input means and output means; second unidirectional coupling means connected between said output means of said third comparator and said input means of said gate to supply set pulses to said gate;

means for resetting said gate each time the voltage applied to said second input means of said first comparator becomes greater than the voltage applied to said second input means of said first comparator; and

third unidirectional coupling means having one end connected to said output means of said gate to produce a dicrotic notch voltage pulse at its other end.

2. The circuit of claim 1 wherein each of said first, second and third unidirectional coupling means comprises a serially connected capacitor and diode.

3. The circuit of claim 1 wherein said differentiator circuit comprises

an operational amplifier having first and second inputs and an output;

a first capacitor and a first resistor serially connected between said second input of said amplifier and said transducer, said first input being connected to circuit common;

a second capacitor and a second resistor connected in parallel between said output and said second input of said operational amplifier.

4. The circuit of claim 3 and including first and second zener diodes connected in back to back relationship across said second resistor.

5. The circuitry of claim 1 and including impedance matching means interposed between said first comparator and said unidirectional low pass filter.

6. The circuitry of claim 1 wherein said unidirectional low pass filter comprises a diode and a resistor connected in parallel relationship between the output of said first comparator and the input of said second comparator, a capacitor being connected from the input of said second comparator to circuit common.

7. The circuit of claim 1 wherein said gate means comprises a first multivibrator having an output, a set input and a reset input, said second unidirectional coupling means being connected to the set input of the first multivibrator, said third unidirectional coupling means being connected to the output of said first multivibrator; and wherein said means for resetting said gate comprises a second multivibrator having an output, a set input and a reset input;

fourth unidirectional coupling means connected between the output of said second multivibrator and the reset input of said first multivibrator;

fifth unidirectional coupling means connected between the set input of said second multivibrator and said output of said first comparator; and means connecting said other end of said first unidirectional coupling means to the reset input of said second multivibrator.

8. The circuitry of claim 7 wherein said fourth and fifth unidirectional coupling means each comprise a serially connected capacitor and diode.

9. The circuit of claim 1 wherein said first and third comparators each comprise an operational amplifier having an output and input means; a resistor and a zener diode serially connected between each amplifier

output and circuit common, the output of each comparator being the voltage between the resistor and the zener diode, said input means of the first amplifier being connected to said low pass filter circuit and said input means of the second amplifier being connected to said high pass filter.

10. The circuit of claim 9 wherein said input means of said first amplifier comprises first and second inputs, and said low pass filter circuit comprises a resistor having one end connected to the second input of said first amplifier to the other end adapted to be connected to said transducer and a capacitor connected from said second input to circuit common; said second input adapted to be connected to said transducer.

11. Apparatus for processing an electric analog voltage of an arterial pressure wave as generated by a transducer comprising;

- means for filtering said electrical analog to remove components above a predetermined frequency and to introduce a time lag;
- means for producing a square voltage pulse each time said electrical analog is greater in magnitude than the filtered analog;
- means causing the trailing edge of each of said square voltage pulses to decay exponentially;
- means for producing a square voltage pulse each time said exponential decay goes below a predetermined level and lasting until the occurrence of the leading

- edge of the next of said first mentioned square pulses;
- initial systole output means;
- means for coupling the leading edge of said second mentioned square wave pulses to said initial systole output means;
- means for differentiating said electrical analog;
- means for filtering the differentiated analog to remove components below a predetermined frequency, the differentiated and filtered analog being essentially a second derivative waveform with respect to time of said analog;
- means responsive to said last named means for producing a switching voltage which switches from a high-to-low-to-high value in accordance with changes in slope of said analog;
- gate means;
- second coupling means for transmitting said switching voltage to an input of said gate means;
- means for opening said gate once each cycle for the first pulse received from said second coupling
- means to produce a square voltage pulse at an output of said gate;
- dicrotic notch output means; and
- third coupling means for passing a wave front of predetermined polarity from said output of said gate means to said dicrotic notch output means.

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