AN ELECTRONIC CIRCUIT THAT DETECTS LEFT VENTRICULAR EJECTION EVENTS BY PROCESSING THE ARTERIAL PRESSURE WAVEFORM

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AN ELECTRONIC CIRCUIT THAT DETECTS LEFT VENTRICULAR EJECTION
EVENTS BY PROCESSING THE ARTERIAL PRESSURE WAVEFORM

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An electronic circuit processes the arterial blood pressure waveform to
produce discrete signals that coincide with the beginning and end of left
ventricular ejection (LVE). A typical arterial pressure waveform is shown in
figure 1. LVE begins at the time when the blood pressure rapidly increases
due to the heart pumping blood through the aortic valve into the arteries.
LVE ends at the waveform dicrotic notch which is a pressure disturbance caused
by aortic valve closure. By detecting these two events the circuit provides
timing signals for use in measuring the left ventricular ejection time (LVET)
and for computers that monitor cardiovascular systems.

Openings and closures of the aortic valve are easy to identify visually
in figure 1, but difficult to detect electronically, especially when the cir-
cuit (or computer) has no memory to review past events. To cover a wide
variety of situations, the detector must operate for heart rates between 50
and 200 beats per minute and operate reliably for the waveforms that can re-
sult from abnormal circulatory dynamics, from irregular heart beats, and
from breathing pressures. A detection process based on slope measurements
alone doesn't work, since it also detects extraneous oscillations. The
approach of using a signal that is initiated when the pressure exceeds its
average value has disadvantages of producing late signals and false signals
when the pressure wave oscillates through the average value.

The circuit for detecting the beginning and end of LVE is shown in
figure 2. Signal A is an electrical input signal proportional to the blood
pressure in the arteries near the heart. The portion above the dashed line

produces a positive pulse at output terminal K when the aortic valve opens at the beginning of LVE. The process below the dashed line produces a negative pulse at K when the valve closes at the end of LVE.

Beginning of LVE is determined by first comparing signal A to signal B. The comparator switches C in a negative direction when A initially increases at the beginning of LVE.

Signal C is quite independent of low frequency components caused by breathing, since the cutoff frequency for signal B is more than two octaves above the breathing frequency. However, C is affected by high frequency components that can result from abnormal circulatory dynamics. Oscillations with frequency content of 6 to 15 hertz can cause A to cross over B and result in C switching during the cardiac cycle. To avoid such problems, C is processed by a pulse-width-discriminator that makes E independent of high frequency switching in signal C.

Signal E switches in the negative direction only once each cardiac cycle at the beginning of LVE. This action produces a positive pulse at output terminal K.

The circuit for detecting the end of LVE is shown below the dashed line. The objective is to produce a negative pulse at terminal K coinciding in time with the positive inflection point that occurs at the leading edge of the dicrotic notch.

Signal H is related to the second derivative of A with respect to time. Signal H changes polarity at the inflection points in the low frequency portion of A. Positive inflection points are signified by signal I switching to a negative voltage. Since waveform A has several inflections, signal I switches several times each cardiac cycle.

The proper inflection point is selected by a logic circuit that uses two flip-flops (operational amplifiers dominated by positive feedback). Flip-flop 1 is switched positive by C and negative by E. This arrangement results in F switching positive only once each cardiac cycle just prior to the dicrotic notch.

When signal F switches to a positive voltage, signal J switches to a negative voltage. The next positive inflection in A switches I to a negative voltage, switches J to a positive voltage, and produces a negative pulse at output terminal K. This output pulse coincides with the end of LVE.

Inflections after the dicrotic notch have no effect on J, since J remains latched at a positive voltage until F switches positive in the next cardiac cycle.

The circuit of figure 2 operates reliably for heart rates between 50 and 200 beats per minute and for the variety of waveforms that can result from abnormal circulatory dynamics, from irregular heart beats, and from breathing pressures.
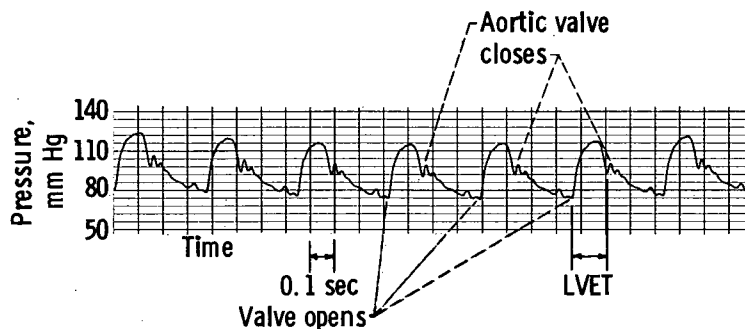
Aortic valve closes

Pressure, mm Hg

140
110
80
50

Time

0.1 sec

Valve opens

LVET

Figure 1. - Typical arterial pressure waveform.

OP AMPS: ±5 mA, ±10 V OUTPUT; INPUT > 1 MΩ
RESISTORS, KILOHMS
CAPACITORS, MICROFARADS

FOLLOWER

PULSE-WIDTH-DISCR.

COMPARATOR 1

A
120
B
1
LOW
PASS
10
C
9V

2
C
50
D
3
4
E
2
.1
100

PULSE ADDER

10
K
8
OUTPUT
POSITIVE PULSE AT
BEGINNING, NEGATIVE
PULSE AT END OF
EJECTION

INPUT A

ARTERIAL
PRESSURE
WAVEFORM
$\left(50 \frac{mvolts}{mm\ Hg}\right)$

.001
100

4
10
100
F
2
.001
100

100

1
FLIP-FLOP 1

7
100
2
.1
4
J
2

9V 9V
560
.02

A
1 .1

5
G
HIGH
PASS

.5 H
6
100
2

4 .001
2 100
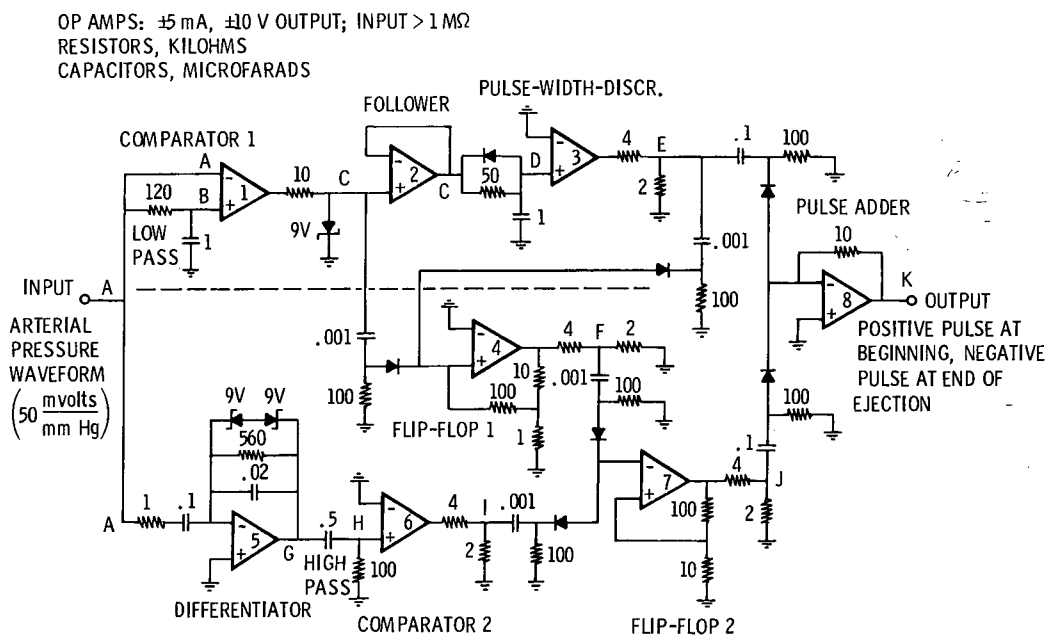
100
10

DIFFERENTIATOR

COMPARATOR 2

FLIP-FLOP 2

Figure 2. - Circuit for detecting left ventricular ejection events.