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# QUARTERLY STATUS REPORT

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Submitted by: Stephen K. Burns
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March 16, 1970



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Research Laboratory of Electronics
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Communications Biophysics--The Temporal Structure of Electrophysiological Data
March 16, 1970

## A. Research Progress

Most of our effort has been focused on the electrical characterization and display of ectopic heartbeats appearing in the electrocardiogram. The greater part of this effort has been spent in developing data acquisition instruments.

1. Analog Interface

The design of the analog input-output interface for our digital data processor has been completed. This interface can accommodate 16 analog input channels, 16 digital inputs, 4 fully buffered analog output channels, and 16 digital outputs. Construction of the analog input-output circuitry has been completed and is operating nicely. We anticipate repackaging it into a companion cabinet to the Tektronix model 601 display oscilloscope. This system will fit into a $10\frac{1}{2}$-inch rack cabinet and is highly portable.

## B. Senior Thesis Students

The following M.I.T. fourth-year students in Electrical Engineering are pursuing their Senior Thesis within our laboratory under the joint supervision of Professors Burns and Mark:

Collesidis, Robert: A System to Detect Ectopic Heartbeats

Conrad, Chester: Development of a Perfusion System for Isolated Organs

Gessman, Lawrence: Vectorcardiographic Characterization of Ectopic Heartbeats

Hamerly, James: The Detection and Recording of Ectopic Heartbeats

Jackson, Jerome: A Cardiac Monitor with Audio Output

LaBresh, Kenneth: Pulse Wave Velocity as a Measure of Arterial Blood Pressure

Smith, David J.: Analysis of Cortical Evoked Potentials Recording of Hepatic Encephalopathy Subjects

Walters, Joseph: Signal Preprocessing as an Aid to Real-Time ECG Analysis

C. The following M.I.T. graduate students in Electrical Engineering are pursuing their Master thesis research within our laboratory:

| | |
|---|---|
| Gaimon, Barry: | Waveform manipulation using a real-time digital data processor. |
| James, Thomas: | A tape-recording system for low-frequency data incorporating compensation for speed-variations in the tape transport. |
| Jergens, Paul: | Waveform acquisition, storage and detection using shift-register memories. |
| Kress, David: | In Vivo Monitoring of Interstitial Fluid Electrolytes. |

D. Publications: (copy attached)

David L. Sulman, "PVC Detector" Quarterly Progress Report No. 96, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1970, pp. 242-249.

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QUARTERLY PROGRESS REPORT NO. 96 January 15, 1970

RESEARCH LABORATORY OF ELECTRONICS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge, Massachusetts

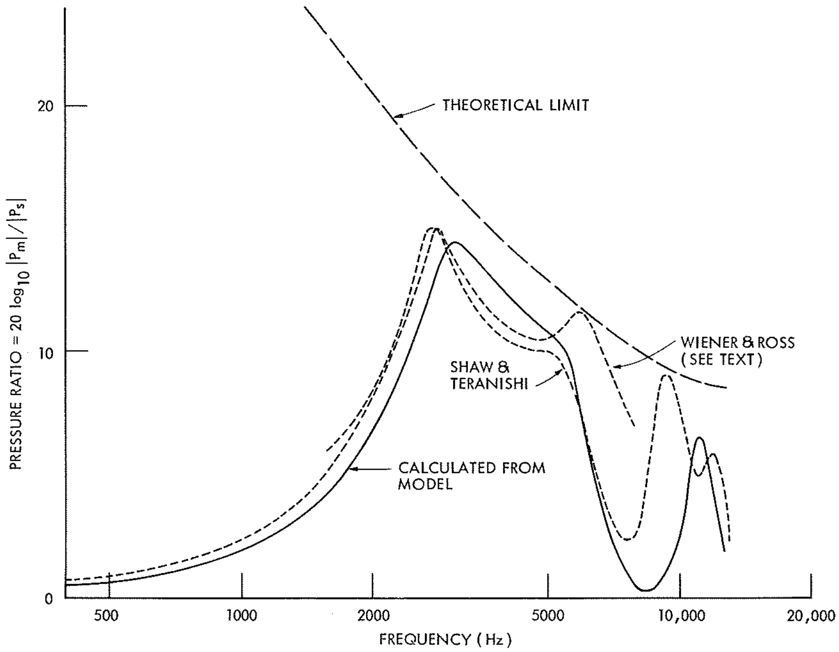


Fig. XXVII-6. Pressure ratios.

The degree of match, however, is somewhat better than one might superficially infer from Fig. XXVII-4. Indeed, the transmission coefficient $|t|^2$ is approximately -2 dB over the range 3 kHz < f < 5 kHz as shown in Fig. XXVII-5. These results are translated into more familiar terms in Fig. XXVII-6. The ordinate in Fig. XXVII-6 is the ratio of the magnitude of the pressure at the drum, $|P_m|$, to the pressure, $|P_s|$, that would be measured just external to the concha if the concha were closed with a rigid plug. (Over most of the frequency range of interest, the wavelength is sufficiently small compared with the radius of the head that $|P_s|$ will be approximately twice the magnitude of the free-field pressure for a wave coming directly at the ear, i.e., $\theta = \phi = \pi/2$.) The maximum possible pressure ratio is readily calculated under the assumption that all of the available power is absorbed in the load. That is,

$$\text{Max } \frac{|P_m|^2}{|P_s|^2} = \frac{R_m^2 + X_m^2}{4R_m R_s},$$

where $R_s$ is the real part of the radiation impedance looking out from the concha. This ratio is plotted as the dashed curve labeled "Theoretical Limit" in Fig. XXVII-6. The actual pressure ratio (the solid curve of Fig. XXVII-6) differs from the theoretical limit by the factor $|t|^2$ of Fig. XXVII-5. Thus in the frequency region 3-5 kHz a better impedance match could increase the pressure ratio by only approximately 2 dB. At lower frequencies, however, substantial improvement would be theoretically possible at least at any one frequency. (There are limitations on the width of the frequency band over which a relatively good match between complex load impedances can be realized with a passive matching network.[4,5] The precise nature of these limitations has not been worked out for load impedances of the type corresponding to $Z_a$ and $Z_m$, but it is possible that a better match at low frequencies could be achieved only at the cost of poorer performance in the 3-5 kHz region.)

Figure XXVII-6 also compares the pressure ratio for the model of Fig. XXVII-3 with several measurements on real ears and replicas. (The measurements of Wiener and Ross have been reduced by 6 dB to reflect the difference between $P_s$ and the free-field pressure as discussed above.) No particular effort was made to adjust the parameters of the model to match these observations. In fact, a somewhat better match would probably be obtained with a slightly longer canal. This would reduce the frequencies of both the 1/4 wavelength and 3/4 wavelength resonances near 3 kHz and 10 kHz. The concha is important both in enhancing the effect of the 3-kHz resonance and in providing the shoulder to extend the matched band to 5 kHz.

W. M. Siebert

References

1. F. M. Wiener and D. A. Ross, "The Pressure Distribution in the Auditory Canal in a Progressive Sound Field," J. Acoust. Soc. Am. 18, 401-408 (1946).
2. E. A. G. Shaw and R. Teranishi, "Sound Pressure Generated in an External-Ear Replica and Real Human Ears by a Nearby Point Source," J. Acoust. Soc. Am. 44, 240-249 (1968).
3. J. Zwislocki, "Analysis of Some Auditory Characteristics," in Handbook of Mathematical Psychology, Vol. III, R. D. Luce, R. R. Bush, and E. Galanter (eds.) (John Wiley and Sons, Inc., New York, 1965).
4. H. W. Bode, Network Analysis and Feedback Amplifier Design (D. Van Nostrand Co., Princeton, N.J., 1945).
5. R. M. Fano, "Theoretical Limitations on the Broadband Matching of Arbitrary Impedances," J. Franklin Inst. 249, 57-83; 139-154 (1950).

## B. PVC DETECTOR

A premature ventricular contraction (PVC) is the spontaneous contraction of the ventricles of the heart at an earlier point in the cycle than would occur in normal cardiac rhythm. This is evidenced in the electrocardiogram (EKG) by abnormal wave shape of the QRS complex, the voltage associated with ventricular depolarization. Prematurity is not unique to PVC's, but is also characteristic of superventricular arrhythmias.

PVC's are known to be associated with drug toxicity and various cardiac diseases. The significance of PVC's in the history of a cardiac patient is, at present, a topic of research. The usual practice of examining a short strip of EKG record is inadequate when the frequency of PVC occurrence is low, as is ordinarily the case in the unhospitalized patient. Since the time required to examine records extensive enough for sound statistical data would be prohibitive, the utility of an instrument for automatic PVC detection is clear.

The instrument described in this report was designed to fulfill this purpose. In particular, the feasibility of a scheme for diagnosing abnormal QRS wave shape has been investigated; the detection of prematurity is relatively simple and has previously been implemented with reasonable success. The principal design criteria for the PVC detector described here were minimization of hardware and simplicity of operation. These are important if widespread data are to be accumulated.

The characteristic of QRS wave shape that was utilized was duration; more specifically, the width between baseline crossings of those components of the EKG which meet an amplitude criterion. Cardiac conduction in the case of a PVC is abnormal, and the resulting QRS is generally prolonged. Furthermore, the normal QRS duration is relatively constant for a given patient (unlike, for example, cycle length), and so there is no need for automatic updating of this parameter by the instrument. This considerably simplifies the hardware that is required, as well as the reliability of the device.

## 1. Circuit Description

A block diagram and illustrative waveforms for the PVC detector appear in Fig. XXVII-7. The action of the instrument is to indicate a PVC whenever an EKG component of either polarity with sufficient amplitude exceeds a preset width.

The EKG signal is buffered by the input amplifier, which provides gain adjustment and rudimentary filtering. The principal purpose of the filtering is to attenuate low-frequency baseline shifts in the input signal. The distinction between positive and negative polarity is eliminated in the next stage, which is an absolute-value amplifier or full-wave rectifier. The full-wave rectified waveform is high-passed to remove the DC component and shift the baseline slightly below zero.

The resultant waveform is fed into a pair of comparators. The first of these, the "R-detector," determines whether an EKG component is of sufficient amplitude to be processed. The "zero-crossing detector," on the other hand, produces a high voltage whenever the waveform lies below a fixed threshold close to zero. This voltage is used to reset a linear ramp, the amplitude of which is therefore proportional to the interval since the latest zero crossing of the high-passed, rectified EKG signal (Fig. XXVII-8).

The "width-detector" is a third comparator which produces a negative voltage whenever the ramp waveform exceeds a preset threshold. At this time, an output pulse indicating the occurrence of a PVC is produced, provided that the other input to the gate is

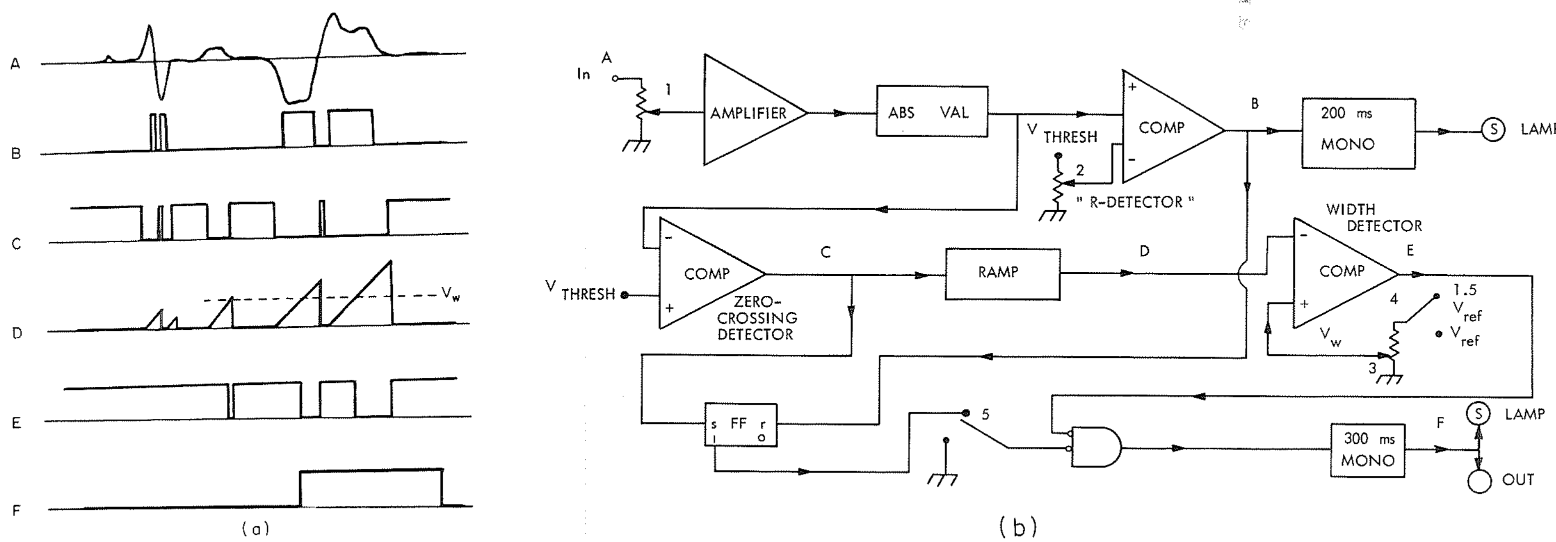


Fig. XXVII-7. PVC detector circuit. Letters correspond to the waveforms illustrated on the left. Numbers correspond to the following controls: (1) gain; (2) R-detector threshold; (3) width threshold; (4) width threshold "X1.5" switch; (5) amplitude criterion override switch.

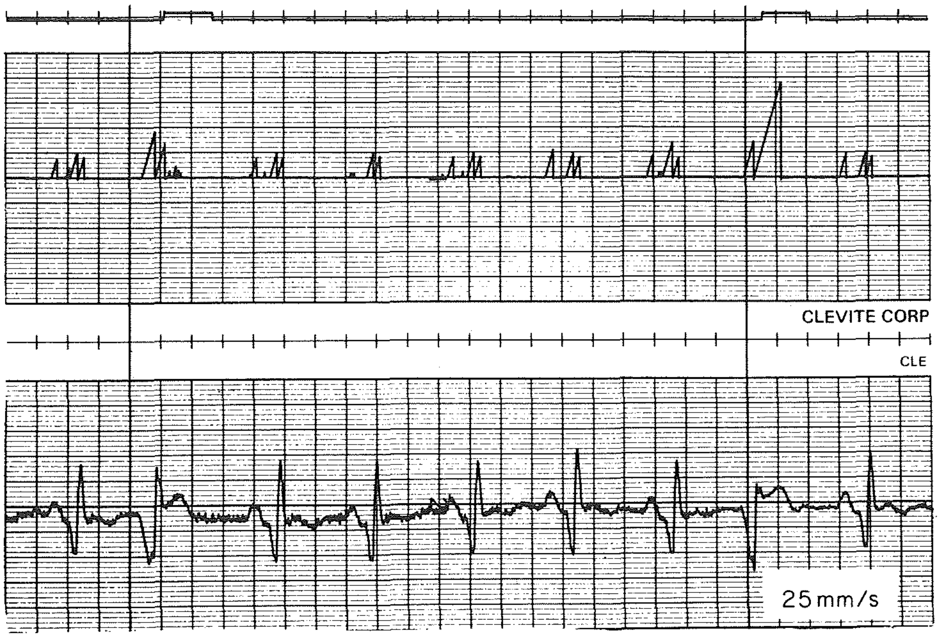


Fig. XXVII-8. Waveform of ramp generator. The output of the ramp generator is shown above the EKG signal used as an input to the PVC detector. Notice that the full width of the first PVC does not register because it dips below the threshold of the zero-crossing detector.

The uppermost trace is the event-marker of the chart recorder used for this record, activated by the detector's output pulse generator through a relay. Both pulses are actually triggered by the first ramp voltage for the corresponding PVC, but the delay of the event-marker actuation makes this unclear.

low. Under normal operation, this condition prevails if the S-R flip-flop has been reset by the R-detector since the latest zero crossing. Thus, an EKG component must meet two conditions to produce an output pulse: it must exceed a preset width and a preset amplitude.

The width and amplitude thresholds are set by the operator, along with the gain of the input stage. The instrument's controls were designed to simplify the experimental procedure as much as possible, and avoid the need for auxiliary monitoring equipment. The outputs of the R-detector and gated width detector are wired to lamps mounted on the control panel. Observation of the R-detector output allows the operator to adjust the gain by observing the point where the R-detector (at maximum threshold) is just activated once each cardiac cycle. This ensures efficient use of the dynamic range of the system, and avoids the necessity of separate adjustment of the zero-crossing threshold.

Once the gain has been set in this fashion, the R-detector threshold can be lowered to process more than one component of each QRS complex. The width-detector threshold is

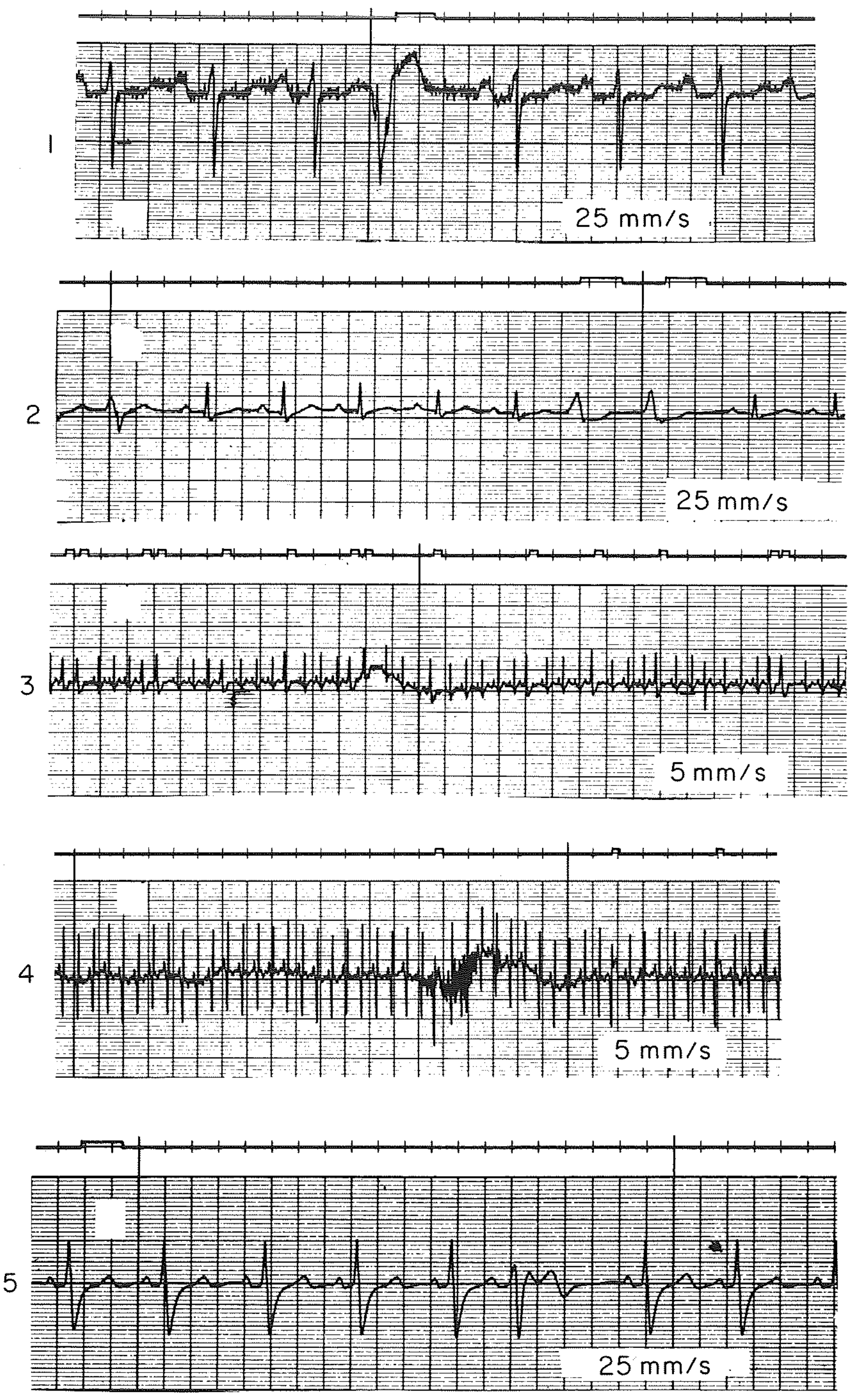
1
25 mm/s
2
25 mm/s
3
5 mm/s
4
5 mm/s
5
25 mm/s

Fig. XXVII-9. Samples of EKG records used in testing the PVC detector. Detector output is shown above each EKG. Strips were recorded at 5 and 25 mm/sec.

1. From record No. 1: Detection of a PVC is shown in the presence of noise.
2. From record No. 3: Two types of PVC are shown. The first type was consistently missed by the instrument, while the second was consistently detected.
3. From record No. 3: Slower recording than above, showing the high incidence of PVC's. Most are of the second type cited above. Also shown is the successful detection of two PVC's in the presence of baseline shift.
4. From record No. 5: Shown are three PVC's correctly detected, one in the presence of considerable noise.
5. From record No. 12: This is the PVC that could not be detected by the instrument. Shown are one false positive and one false negative. The false positives occurred only when the width threshold was lowered in an unsuccessful effort to detect the PVC's.

Table XXVII-1. Summary of test results.

| EKG Record number | True neg. | True pos. | False neg. | False pos. | Failure Rates: PVC's missed: Actual (%) | Failure Rates: PVC's missed: Conf. Limit (%) | Failure Rates: False alarms: Actual (%) | Failure Rates: False alarms: Conf. Limit (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 600 | 16 | 0 | 2 | 0 | 13 | 11 | 28 |
| 2 | 620 | 1 | 0 | 0 | 0 | – | 0 | – |
| 3 | 600 | 184 | 8 | 0 | 4 | 8 | 0 | 1 |
| 4 | 550 | 0 | 0 | 0 | – | – | – | – |
| 5 | 800 | 79 | 2 | 0 | 2 | 8 | 0 | 3 |
| 6 | 690 | 26* | 0 | 3 | 0 | 8 | 10 | 22 |
| 7 | 800 | 7 | 0 | 14 | 0 | 28 | 67 | – |
| 8 | 730 | 15 | 0 | 0 | 0 | 14 | 0 | 14 |
| 9 | 600 | 14 | 0 | 0 | 0 | 15 | 0 | 15 |
| 10 | 720 | 41 | 0 | 2 | 0 | 5 | 5 | 14 |
| 11 | 1470 | 1 | 0 | 0 | 0 | – | 0 | – |
| 12 | 200 | 0 | 11 | 14 | 100 | – | 100 | – |

Key to column headings

True neg.: Normal beats so adjudged by the instrument.

True pos.: PVC's correctly diagnosed by the instrument.

False neg.: PVC's not detected by the instrument.

False pos.: Output pulses of the instrument without an actual PVC on the EKG.

PVC's missed: The ratio of (false neg.)/(true pos. + false neg.), expressed as a percentage. In other words, the fraction of PVC's missed by the instrument.

False alarms: The ratio of (false pos.)/(true pos. + false pos.), expressed as a percentage. In other words, the fraction of alarms (output pulses) which are false.†

Conf. limit: The statistical upper limit of the true failure rate, asserted with 90% confidence. Based on a sample corresponding to the denominator term for the two classes of failure cited above. Not computed for sample sizes ≤2 or for actual failure rates >50%.

*Actually nodal premature beats with widened QRS.

†A considerably more optimistic figure would be the ratio of (false pos.)/(true neg. + false pos.), or the fraction of normal beats incorrectly adjudged PVC's. This would not be as meaningful as the figure cited, which essentially answers the question, "When the fire bell rings, what are the chances that there really is a fire?"

then adjusted by finding the setting where every QRS just elicits an output pulse, as observed through the second lamp. A switch is then thrown which sets the threshold at 1.5 times this setting. Such a procedure is usually adequate for distinguishing PVC's, but the threshold can be lowered from this point if required.

2. Preliminary Results

A series of prerecorded EKG records was used to evaluate performance of the PVC detector. These were selected for variability in the recognition problems presented, and not for being typical of EKG's expected in practice; hence, the results are exploratory in nature. Samples of the records are shown in Fig. XXVII-9, and a summary is presented in Table XXVII-1.

In most cases, the failure to obtain statistically significant favorable results was attributable to small sample size; 10 min of EKG was run for each record, but in many the number of PVC's was small. The principal cause of genuine failures by the detector was baseline shift too sudden to be eliminated by the highpass filtering of the input stage. It is doubtful that more extensive filtering of a linear nature would remove this source of false alarm, since the frequency content of this particular artifact is similar to that of a genuine PVC.

On the other hand, the incidence of false negative responses by the instrument was acceptably low for all but one record. The QRS for PVC's of this record was visibly abnormal, but it had no single component that could simultaneously meet the width and amplitude criteria for detection. It is clear that the recognition scheme evaluated here was invalid for an EKG record of this type (Fig. XXVII-9 (5)).

The next phase of evaluation would be to test the instrument's performance with EKG records more representative of the actual population. If results are satisfactory, the simple addition of a digital counter should enable the detector to be used in acquiring data on cardiac arrhythmia.

[The research described in this report was part of a Master's thesis in the Department of Electrical Engineering, M.I.T., supervised by Professor S. K. Burns.]

D. L. Sulman