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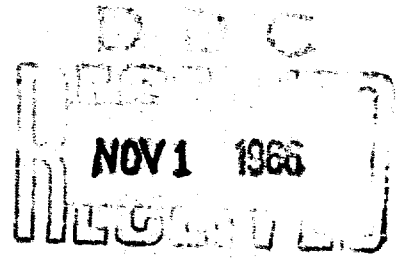
DESIGN AND DEVELOPMENT OF AN AUTOMATIC INDIRECT BLOOD PRESSURE MONITORING DEVICE

JAMES E. ALLRED, M.S.E.E.

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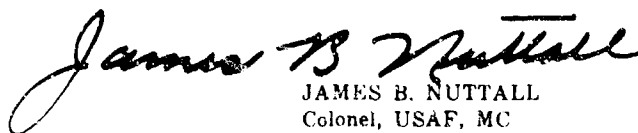
DESIGN AND DEVELOPMENT OF AN AUTOMATIC INDIRECT BLOOD PRESSURE
MONITORING DEVICE

JAMES E. ALLRED, B.S.E.E.
JACK B. JOHNSON, M.S.E.E.

FOREWORD

This report was prepared by the Biomedical Engineering Branch, USAF School of Aerospace Medicine, under task No. 632001. The work was accomplished between February 1964 and December 1964. The paper was submitted for publication on 27 June 1966.

This report has been reviewed and is approved.



JAMES B. NUTTALL
Colonel, USAF, MC
Commander

ABSTRACT

The design of an automatic electronic blood pressure recording device is described. This device, which applies pressure only slightly higher than the systolic pressure of the subject, is programmed to record the Korotkoff sounds while the occlusion cuff is being inflated. The system may be programmed to monitor blood pressure at any predetermined rate from intervals of one minute to several minutes, or it may be initiated manually.

Proper design of circuitry for maximum signal-to-noise ratio required a knowledge of the frequency range of the complex Korotkoff sound waveform. This information was obtained by recording the K sounds from four subjects and analyzing the waveforms for energy content vs. frequency. These data are also presented.

DESIGN AND DEVELOPMENT OF AN AUTOMATIC INDIRECT BLOOD PRESSURE MONITORING DEVICE

I. INTRODUCTION

Many automatic blood pressure recording devices utilized on human subjects operate by inflation of an occlusion cuff to some predetermined pressure level which is then slowly released until the systolic and diastolic pressures can be recorded. This predetermined pressure level has to be quite high (say, 250 mm. Hg) to cover the wide range of blood pressures encountered, but in some cases during heavy exercise this pressure is not high enough to record systolic pressures. High monitoring rates (one per minute, for example) over long periods of time produce considerable discomfort to the subject. Another apparent disadvantage of some of these systems is that there is a great amount of movement artifacts during exercise of the subject.

The design goal of this project was to provide an automatic blood pressure device which would (1) provide minimal discomfort, (2) provide a wide dynamic pressure range, and (3) reduce movement artifacts under dynamic stress testing.

II. SYSTEM DESIGN AND OPERATION

The measurement cycle of the system shown in figure 1 (also shown in block diagram form in figure 2) is started in the automatic mode by the one-minute timer or in the manual mode by pressing the manual reset switch. When either of these events occurs, the 3-way air valve allows pressure to be applied to the cuff and pressure transducer at a rate determined by the flow valve. As the cuff is being inflated, the Korotkoff sounds are obtained from a recording microphone and are superimposed on the voltage from the pressure

transducer which is proportional to the applied pressure. The voltage from the pressure transducer is also applied to the pressure level detector which determines the pressure at which the occlusion cuff will deflate. The K sounds and cuff pressure outputs (0 to 2.5 v. max.) have been designed to be compatible with most FM magnetic tape recorders.

Amplifier and filter

The differential amplifier in figure 1, which was designed to accommodate long input connection leads, has a common mode rejection of 65 dB, an overall voltage gain of 70 dB, and an equivalent input noise level of approximately $1 \mu\text{v}$. The amplifier is followed by four stages of low-pass active filtering designed for a total slope of 48 dB/octave with a rolloff beginning at 40 Hz. The overall frequency response of the amplifier and filter, as shown in figure 3, provides an adequate range for the Korotkoff sounds and reduces the level of 60 Hz to -9 dB relative to the bandpass. The filter was designed to have a sufficiently narrow bandpass to reduce noise from movement artifacts but not so narrow as to produce filter ringing. Reasons for using this bandpass will be discussed in section III.

Pressure transducer

The pressure transducer employed requires a differential supply voltage and provides an output from 0 to 5 volts d.c. for pressures ranging from 0 to 300 mm. Hg; however, any pressure transducer which could produce a linear output for the pressure range given would be suitable. The output of this transducer is added to the amplified and filtered Korotkoff sounds at the summing amplifier.

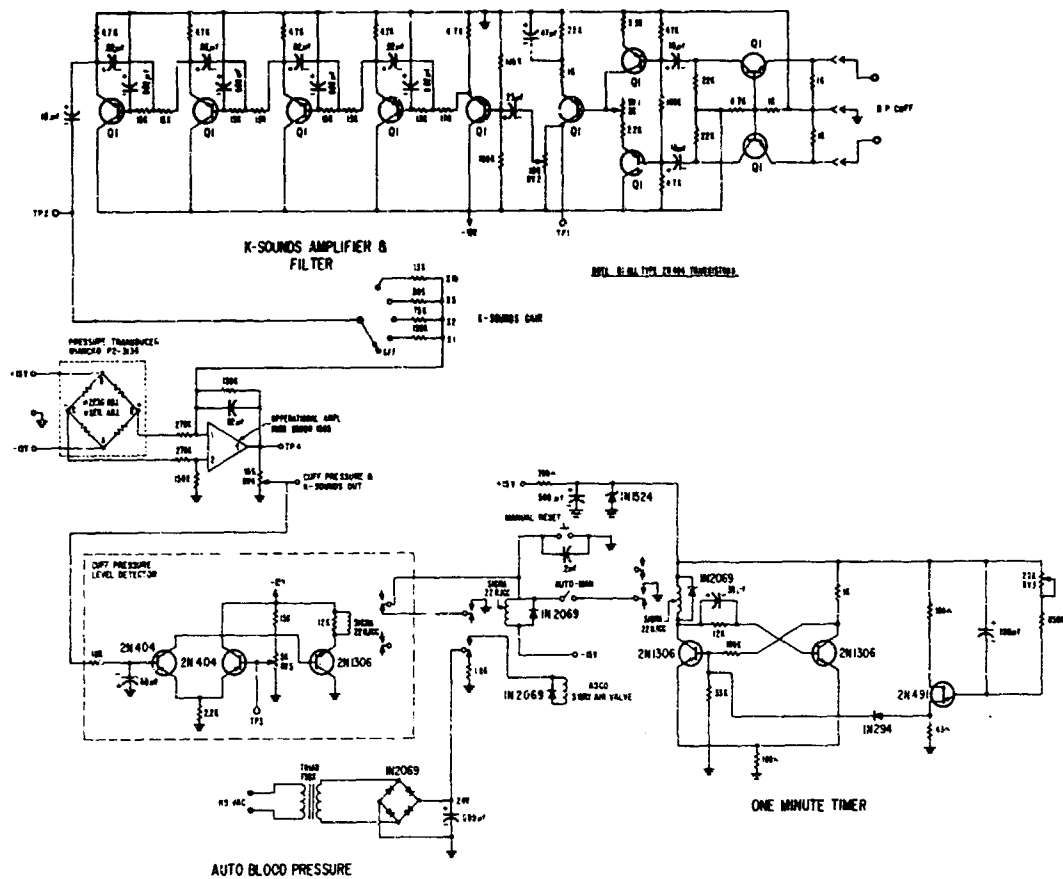


FIGURE 1

Schematic diagram of amplifier and filter.

Summing amplifier

The summing amplifier, a d.c. operational amplifier, provides the combined cuff pressure and Korotkoff sounds at a low-output impedance (200 ohms). The output is adjustable through RV4 to provide the desired level for recording. The output is also fed to the pressure-level detector.

Pressure level detector

During system operation the pressure level detector receives a voltage from the summing amplifier (Burr-Brown model 1503) which is proportional to the pressure applied to the cuff. Variable resistor RV5 is calibrated against an

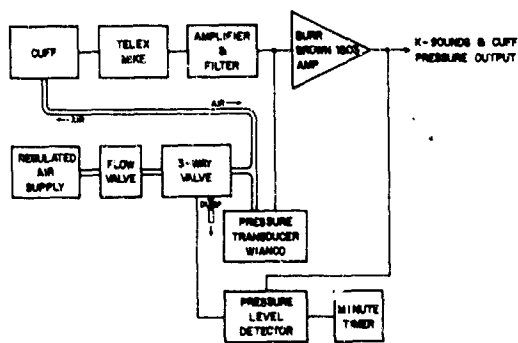


FIGURE 2

Automatic blood pressure system block diagram.

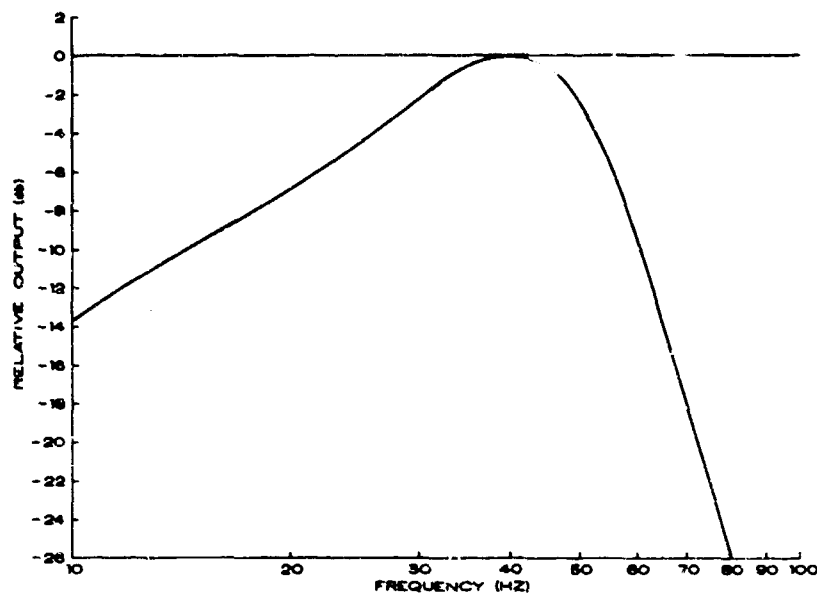


FIGURE 3

Overall response curve for amplifier and filter.

aneroid or mercury manometer from 0 to 300 mm. Hg. When the pressure applied to the cuff reaches the pressure setting on RV5, the level detector releases the voltage applied to the 3-way valve, and the pressure cuff is deflated. Adjustment of RV5 allows the operator to make an initial setting of the maximum pressure applied to the occlusion cuff. This is normally adjusted to 5 to 10 mm. Hg above the systolic pressure of the subject and need not be readjusted for any one subject.

Timing device

The timing device utilizes a unijunction oscillator and Schmitt trigger to provide a one-minute output which recycles the system operation when in the automatic mode. The timing accuracy is approximately one second/hour and can be adjusted at RV3. Although a one-minute timer is used to generate the automatic cycle of the blood pressure device, any convenient timer (for example, one per hour) may be used.

III. EXPERIMENTS AND RESULTS

Korotkoff sound frequency spectrum

The design of the circuitry for the maximum signal-to-noise ratio required determination of the frequency content of the complex Korotkoff sound waveform (K sounds), which was accomplished in the following manner. A recording microphone (Telex model RTX-04) was first attached to the diaphragm portion of a stethoscope as shown in figure 4 and calibrated in an anechoic chamber using the test setup of figure 5. Korotkoff sounds were then obtained from four subjects by placing the calibrated microphone under an occlusion cuff over the brachial artery (see fig. 6) and recording the K sounds on a Dacord FM tape recorder. The recorded K sounds obtained were then analyzed for frequency content using the test setup of figure 7.

Korotkoff sound tests and results

Data obtained from microphone calibration (see table I) are shown as a corrected microphone and amplifier response which represents



FIGURE 4

Photograph of microphone attached to stethoscope.

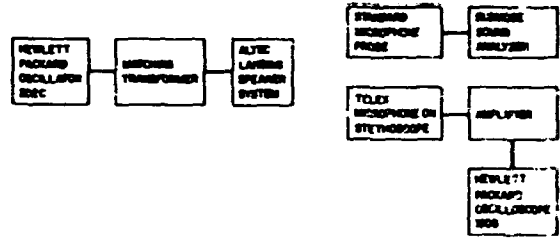


FIGURE 5

Instrumentation test setup for microphone calibration.



FIGURE 6

- A. *Method for attaching microphone to holding cuff.*
- B. *Attaching microphone to the subject.*

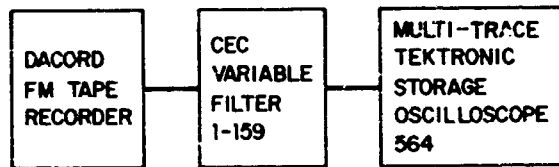


FIGURE 7

Test setup for analyzing frequency content of K sounds.

a "flat" response related to the laboratory standard microphone and a Rudmose sound analyzer. Accurate data below 40 Hz were not obtainable owing to signal distortion from the Telex microphone. The response of the recording microphone is shown in figure 8.

Tabulated data of the tests conducted on the K sounds for frequency content shown in table II have been corrected to the microphone response curve of figure 8. Each column gives the relative K sound energy spectrum vs. frequency for the four subjects. Since there is little variation of K sound energy level between subjects, an average column for the four subjects is also shown in table II and is presented graphically in figure 9.

TABLE I

Telex microphone and amplifier calibration*

Frequency (Hz)	Standard microphone and Rudmose sound analyzer output	Amplifier and Telex microphone output	Corrected amplifier and microphone response
		(decibels)	
40	-1.4	-24.4	23
45	-1.15	-20.0	13.85
50	-1.25	-18.06	16.81
55	-0.98	-12.0	11.02
60	-0.65	- 7.96	7.31
65	-0.40	- 6.0	5.6
70	- 0.29	- 3.1	2.81
75	-0.50	- 5.2	4.7
80	-0.31	- 3.74	3.43
85	-0.10	- 1.94	1.84
90	0.02	0	-0.02
95	0.03	0	-0.03
100	0	0	0

*All measurements are referenced to 100 Hz.

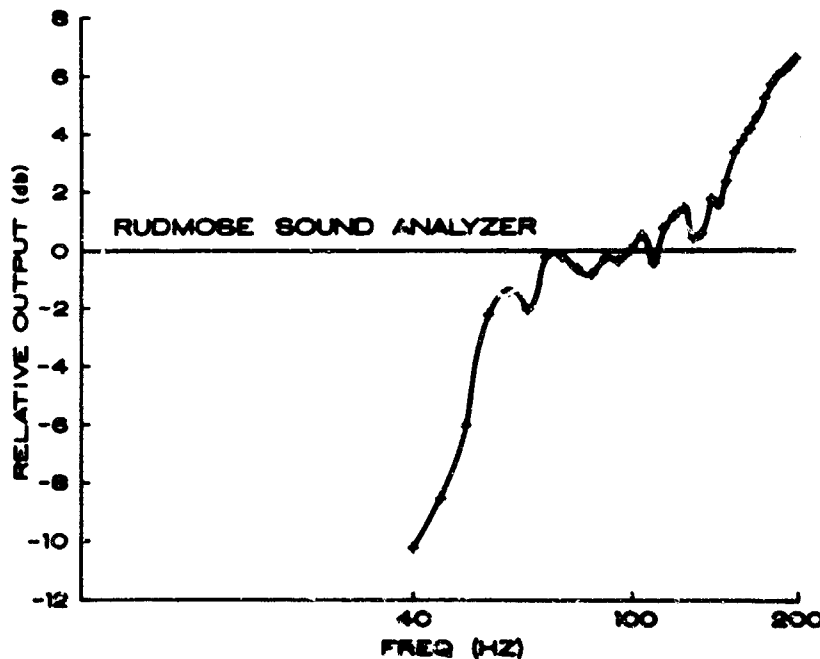


FIGURE 8

Composite calibration curves for Telex microphone and amplifier.

TABLE II
Corrected Korotkoff sound energy level*

Frequency (Hz)	Corrected value	K ₁	K ₂	K ₃	K ₄	K Av.
		(decibels)				
40	23	35.2	35	33.4	32.85	34.2
45	18.85	31	28.8	31.2	31.35	30.5
50	16.8	26.8	24.4	31.2	31.0	28.4
55	11.02	25.2	21.0	27.7	25.5	24.8
60	7.31	23.3	20.6	21.7	21.1	21.6
65	5.6	20.4	18.8	20.0	17.6	19.2
70	2.8	14.8	12.8	14.6	14.3	14.1
75	4.7	14.7	12.3	13.5	14.5	13.7
80	3.43	10.6	7.43	10.38	13.23	10.4
85	1.84	7.04	5.4	6.29	8.59	6.8
90	- 0.02	4.2	3.2	1.78	5.5	3.7
95	- 0.03	2.2	2.2	1.0	3.2	2.1
100	0	0	0	0	0	0

*All measurements are referenced to 100 Hz.

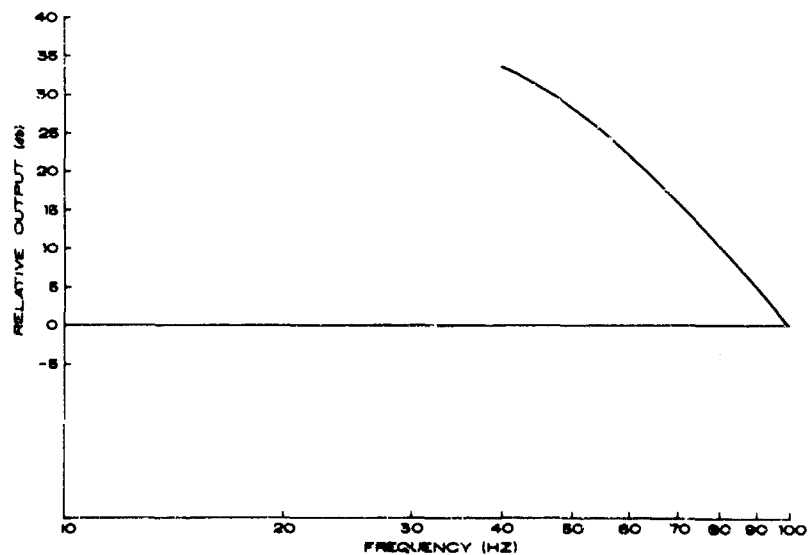


FIGURE 9
Average Korotkoff energy level vs. frequency.

Data are not shown above 120 Hz for obvious reasons. Tests were actually conducted up to 400 Hz, but no significant amount of signal was present at these frequencies. It is unfortunate that the recording microphone did not respond adequately below 40 Hz; however, it may reasonably be concluded upon inspection of figure 9 that the most significant portion of energy contained in the Korotkoff sounds is below 55 Hz.

Since the objective of this experimentation was to produce circuitry which would provide maximum signal-to-noise ratio and not to faithfully reproduce the Korotkoff sound waveform, no attempt was made to differentiate between the diastolic and systolic frequency spectrums. Experiments conducted by Rauterkus et al.¹ coincide with the conclusion of the report—i.e., the most significant energy level is below 55 Hz. These experiments were performed by conducting a Fourier analysis on the complex Korotkoff waveforms of several subjects.

IV. DISCUSSION

The automatic electronic blood pressure monitoring device described is presently being used in a bed rest-exercise study at the School

¹Rauterkus, T., J. F. Feltz, and J. W. Fickes. Frequency analysis of Korotkov blood pressure sounds using the Fourier transform. SAM-TR-66-8, Feb. 1966.

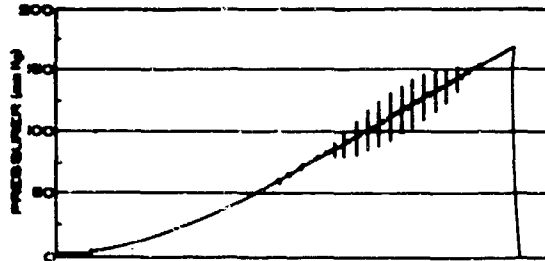


FIGURE 10

Typical blood pressure measurement.

of Aerospace Medicine. An additional timer was employed to provide a measurement every 15 minutes. After the subject has been instrumented and the maximum pressure level set, the subject's blood pressure can be recorded once every 15 minutes while unattended. A modified version of this device was also successfully employed in a dynamic stress testing area where it was required to monitor and record the blood pressure of the subject each minute while exercising. A graphical write-out of a typical blood pressure measurement is shown in figure 10.

It is felt that this initial study in electronic blood pressure monitoring and the developed prototypes should form the basis for further research and development in indirect blood pressure monitoring.

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