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EVALUATION OF NONINVASIVE MEASUREMENT METHODS AND SYSTEMS FOR APPLICATION IN VITAL SIGNS DETECTION:

Part 2. Breadboard Design of a Vital Sign Detector

Charles S. Lessard, Ph.D.
Wing Chan Wong, M.S.
Andrew Yee, B.S.

Bioengineering Program
Industrial Engineering Department
Texas A&M University
College Station, TX 77843

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NOTICES

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This report has been reviewed and is approved for publication.

YASU TAI CHEN, M.S.
Project Scientist

F. WESLEY BAUMGARDNER, Ph.D.
Supervisor

JEFFREY C. DAVIS, Colonel, USAF, MC
Commander

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In the event of chemical warfare, military medical technicians must be able to identify and treat victims exposed to harmful chemical agents. To determine which victims are in need of immediate treatment, a diagnostic tool is needed to help medical technicians in the performance of triage. An evaluation of current literature on noninvasive techniques and systems for physiological measurements indicates that the most promising methods/systems are:

(1) an electromechanical device such as an electronic stethoscope to measure respiratory and cardiac sounds;

(2) a dry electrode/bioamplifier system to measure the electrocardiogram (ECG);

(3) an infrared device to measure arterial pulse and skin temperature; and

(4) sphygmomanometer/stethoscope to measure blood pressure.

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19. ABSTRACT (Continued)

The throat area appears to be the most accessible body surface for a person in a protective garment, and a combination of electronic stethoscope plus dry electrode may provide the essential information. A suggested breadboard system was fabricated and demonstrated.

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TABLE OF CONTENTS

List of Figures

List of Table

EVALUATION OF NONINVASIVE MEASUREMENT METHODS AND SYSTEMS FOR APPLICATION IN VITAL SIGNS DETECTION: Part 2 BREADBOARD DESIGN OF A VITAL SIGN DETECTOR

INTRODUCTION

In the event of chemical warfare, military medical technicians must be able to identify and treat victims exposed to harmful chemical agents. To determine which victims are in need of immediate treatment, a diagnostic tool is needed to help medical technicians in the performance of triage. This study was divided into Part 1 and 2: Part 1 required a detailed search and evaluation of current literature on noninvasive methods and instrumentation techniques to measure vital life signs [1]. Part 2 describes the fabrication of a prototype system.

The main purpose of the Part 1 was to evaluate current literature on noninvasive methods and instruments in order to provide recommendations on direction of technical development which could lead to a system or device for measuring vital life signs of incapacitated military personnel in a toxic field environment. Specifically, the first aim of the study was to determine the set of physiological parameters most likely to provide the vital life signs necessary to assess the seriousness of a casualty. This assessment involves the concept of triage categorization of casualties according to a priority for further assessment and treatment. A survey of patients encompasses three techniques: (1) establishing adequate airway, (2) checking the patient's breathing pattern, and (3) checking for presence of pulse for heart rate and relative pulse pressure strength. The four physiological measures considered primary vital life signs during an emergency assessment in order of priority are: (1) respiration rate or respiratory sounds, (2) heart rate from the raw cardiac (ECG) signal or sounds, (3) blood pressure, and (4) core temperature.

The second specific aim of the study was to evaluate current noninvasive techniques and systems which could perform desired life signs detection in a field environment without violating the integrity of the protective garment. The results of Part 1 of this final report [1] are summarized in Table 1. The four most promising methods/systems in order of utility ranking are:

(a) an electromechanical device such as an electronic stethoscope to measure respiratory and cardiac sounds;

(b) a dry electrode/bioamplifier system to measure the electrocardiogram (ECG);

(c) an infrared device to measure arterial pulse and skin temperature;

(d) sphygmomanometer/stethoscope to measure blood pressure.

TABLE 1. RESULTS OF UTILITY FUNCTION EVALUATION

Measurement systems	Method X_1	Usefulness X_2	Accuracy X_3	Repeatability X_4	Susceptibility to noise X_5	Weight X_6	Power X_7	Skill level X_8	Training requirement X_9	Total value point
1. Electrodes										
a. Dry	5	10	5	5	2	5	5	5	5	47
b. Wet	0	10	5	5	2	5	5	2	2	36
2. Impedance	5	5	1	5	2	5	2	0	0	27
3. Electric fields	10	10	1	1	0	5	5	5	5	42
4. Electro mechanical	10	10	5	5	2	5	5	5	5	53
5. Ultra-sonics	0	5	3	5	2	5	2	0	0	22
6. Auscultatory	5	10	3	3	2	5	5	2	2	37
7. Electomagnetics										
a. Infrared	5	5	3	3	2	5	5	2	2	32
b. Microwaves	10	5	3	3	0	2	2	0	0	25
8. Magnetic fields	10	10	5	5	2	0	2	2	2	38
9. Nuclear magnetic	10	5	3	3	2	2	0	0	0	25
10. Imaging	10	1	3	3	2	0	0	0	0	19

The throat area appears to be the most accessible body surface for a person in a protective garment, and a combination of an electronic stethoscope plus dry electrodes may provide essential information. A suggested breadboard system was fabricated and demonstrated.

The development of a vital life signs detector must consider the limitations of personnel in a toxic environment, the greatest restriction being protective garments which all personnel must wear, and the need to avoid exposing incapacitated personnel to the contaminated environment. The garment is designed to encapsulate and prevent toxic agents from reaching the man, but, in addition, the garment also limits accessibility to any other body surfaces. Only the area of the throat underneath the protective hood, between the mask and jacket, can be exposed by lifting the front of the hood carefully. Ideally, the vital life signs detector should be noncontact, be noninvasive, and provide as many as possible of the physiological parameters required by emergency teams to assess the condition of incapacitated personnel.

This report fulfills the requirement of Part 2 of the study, the fabrication of a prototype vital life signs detector. The prototype vital life signs detector includes an electronic stethoscope, a set of dry electrodes, and a thermistor probe. This report presents the circuits necessary to obtain respiratory sounds, cardiac sounds, one channel of electrocardiogram, and skin temperature (T_{sk}) measured from the area of the throat.

A neckbrace was used to hold the transducers. Separate signal lines connect the transducers to the electronic circuits enclosed in an aluminum box. The sensors mounted in the neckbrace are shown in Figure 1.

Since the electronic stethoscope is commercially available from Sela and protected by patent right, no discussion of the internal electronic circuitry is presented.

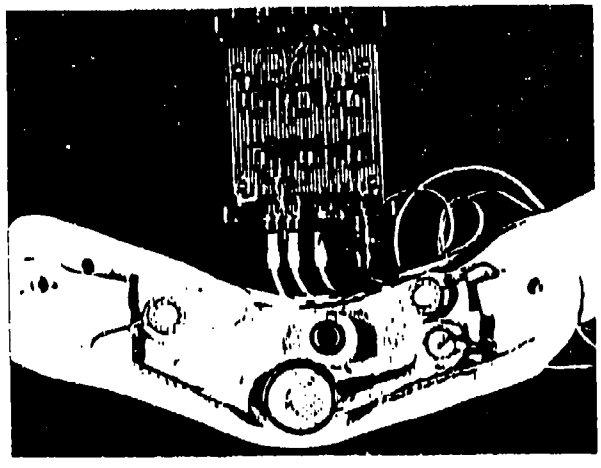

Figure 1. Sensors mounted in neckbrace.

NONINVASIVE, DRY ELECTRODE, ECG SYSTEM

The conventional clinical method for noninvasively recording electrical activity of the heart is the use of disposable electrodes. The two major types of surface electrodes are classified as "wet" or "dry" electrodes. Wet electrodes act as a conductor to establish electrical contact with a nonmetallic portion of a circuit (i.e., the human body). The electrode operates as an electrochemical transducer to change ionic current into electronic current by means of a paste or jelly as a conducting medium through which a current may pass between the skin and electrode [2]. Many problems exist with the "wet" electrodes. First, the skin must be prepared in a manner which produces abrasion of the superficial skin layers [3]. Second, the paste or gel is irritating to the skin, especially in long-term situations. The paste also acts as a site for bacterial fungal growth [3]. Third, 24 to 48 h after application, polarization of the electrode occurs and causes electrode breakdown. Often this polarization, which is caused by lowered skin resistance due to increased epidermal permeability, causes a 5-to-10 μV DC drift and alters the recording [4]. Finally, with "wet" electrodes, body movements must be limited, since movement at the electrode site results in noise (large motion artifacts) on the output [2].

Dry electrodes operate on the principle of displacement current or capacitative coupling with the electrode as one parallel plate and the skin as the other parallel plate. Dry electrodes do not require paste to create a path for ion flow [3], nor is there a need for skin preparation. Additionally, long-term electrode polarization is not exhibited. However, serious problems exist with motion artifacts when the dry electrode is not waterproofed [5,6]. Since active dry electrodes as developed by Ko et al. [7,8] are not commercially available, stainless steel discs were used as dry electrodes. High input impedance precision field effect transistor (FET) operational amplifiers (Op Amp) with low input bias current were configured to provide impedance matching and high common-mode rejection ratio.

A basic problem of cardiac monitoring systems that incorporate dry chest electrodes is that a low impedance ground path to the common electrode is required. A dry electrode, as a common reference cannot be used with conventional differential amplifiers to reach a high enough common-mode rejection ratio (CMRR) in order to effectively reduce the noise of the system. For this reason, Fraden et al. [2] designed a driven ground electrode as a means of increasing the overall CMRR. The driven ground electrode is controlled, or driven, by the common-mode signal into the differential amplifier. This technique ensures that the driven ground electrode is zero with respect to the ground of the system. This technique also results in minimal noise and artifact compared to a nondriven ground electrode [2]. To overcome this problem, and the problem of having to adjust or tune the circuit for maximum common-mode rejection with changes of skin-electrode impedance between subjects, National Semiconductor LH0052CD operational amplifiers were used in a voltage follower configuration between the electrodes and the high CMRR differential circuit. In other words, the voltage follower acts as a "buffer" between the high impedance capacitive electrode and the high CMRR differential

circuit. The desirable characteristics of the voltage follower at its input and output terminals that permit it to function as a buffer are very high input impedance (for the LH0052CD, the input impedance is 10^{12} ohms) and very low output impedance (for the LH0052CD, the output impedance is 75 ohms).

Circuit Description

The components available for implementation of the design include basic operational amplifiers, potentiometers, resistors, and capacitors with 2% to 10% accuracy. The dry electrode ECG monitoring system consists of five stages. The first stage consists of buffer amplifiers in the voltage follower configuration. The second stage constitutes the high CMRR differential amplifier portion of the circuit. The third stage is a fourth-order 60-Hz band-reject active filter. The fourth stage is a fourth-order 3-Hz high-pass Butterworth active filter. A fourth-order 200-Hz low-pass Butterworth active filter constitutes the fifth (final) stage of the monitoring system. An oscilloscope or computer can be coupled to the output of the final stage (*Figs. 2 - 5*).

Buffer Stage

Each dry electrode was connected to a National Semiconductor Corporation LH0052CD precision FET Op Amp connected in a voltage follower configuration as shown in Figure 2. The high impedance of the electrode (greater than 3 megaohm) is seen by the differential amplifier circuit as a 75 ohms low impedance source.

High CMRR Stage

For the high CMRR stage, three National Semiconductor Corporation LH0052CD precision FET Op Amps were connected to form the high CMRR differential amplifier portion of the circuit as shown in Figure 2. These operational amplifiers were chosen for their high input impedance of 10^{12} ohms and very low input bias current of 1.0 pA.

Filter Stages

Following the differential amplifier stage were three active filter stages. The first filter stage consists of dual Op Amps, LM 747, configured to obtain a fourth-order band-reject filter. The center frequency for the band-reject filter was set at 60 Hz. The voltage-controlled voltage source (VCVS) configuration results in unity gain through this stage. By setting center frequency and the desired quality factor (Q) at 10, the resulting filter band width is 6 Hz. Resistance and capacitor values are calculated and the filter is configured as shown in Figure 3. The output of the 60-Hz notch filter is connected to a high-pass filter with the cutoff frequency at 3 Hz.

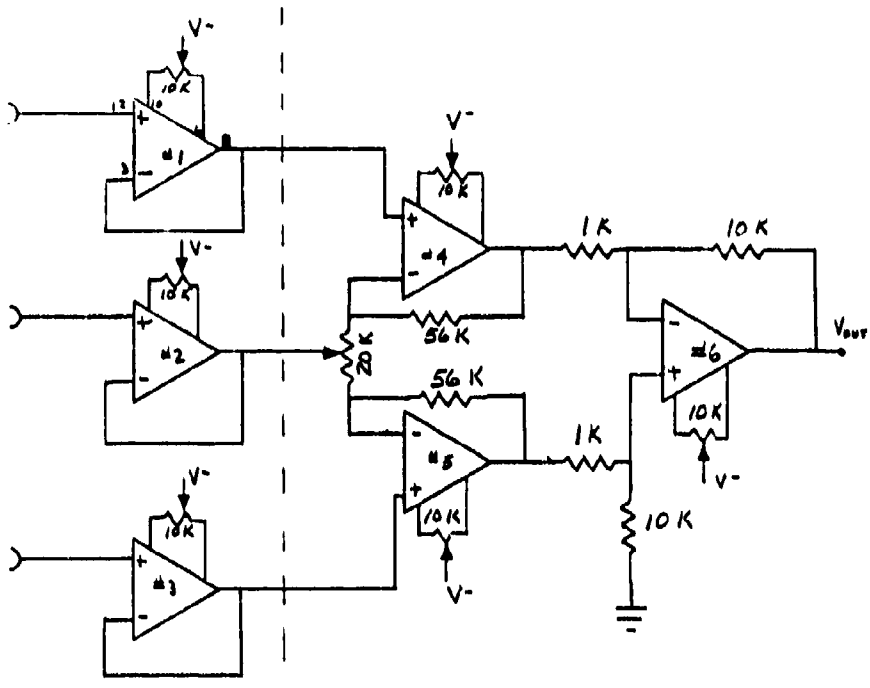

Figure 2. High impedance buffer stage is shown connected to the high common-mode rejection ratio (CMRR) stage. Amplifiers 1 - 6 are high precision FET Op Amps NSC LH0052CD. The output of the CMRR stage is input to the band-reject filter.

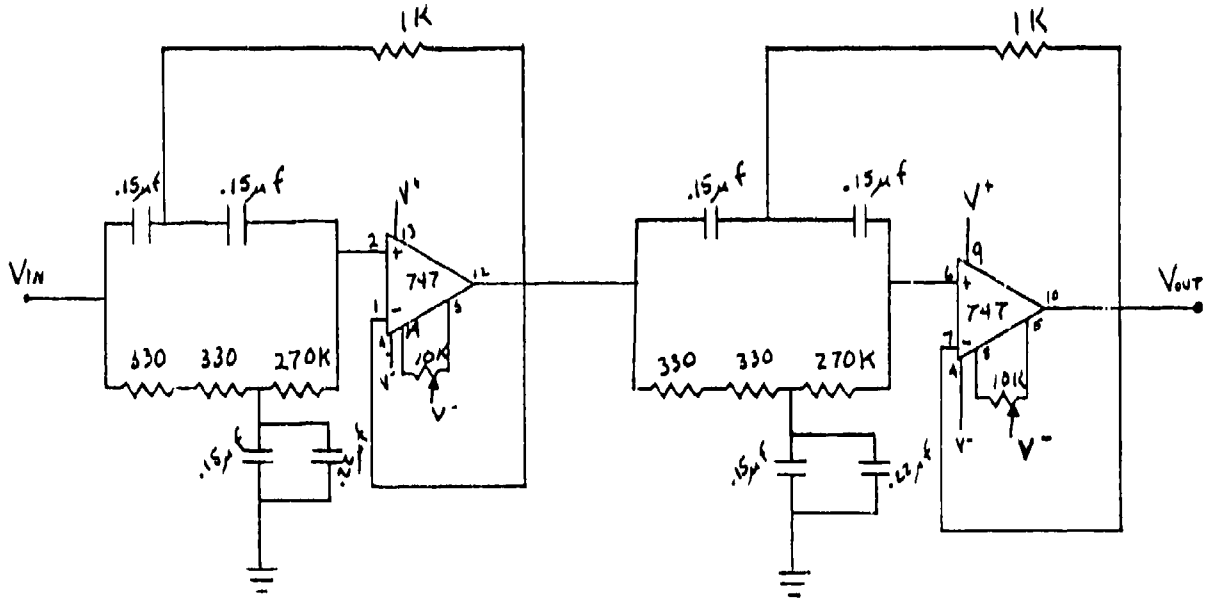

Figure 3. Band-reject filter. A voltage-controlled voltage source (VCVS) configuration is used to obtain a 60-Hz band-reject filter with a bandwidth of 60 Hz and a quality factor (Q) of 10. The output of this stage is connected to the highpass filter stage.

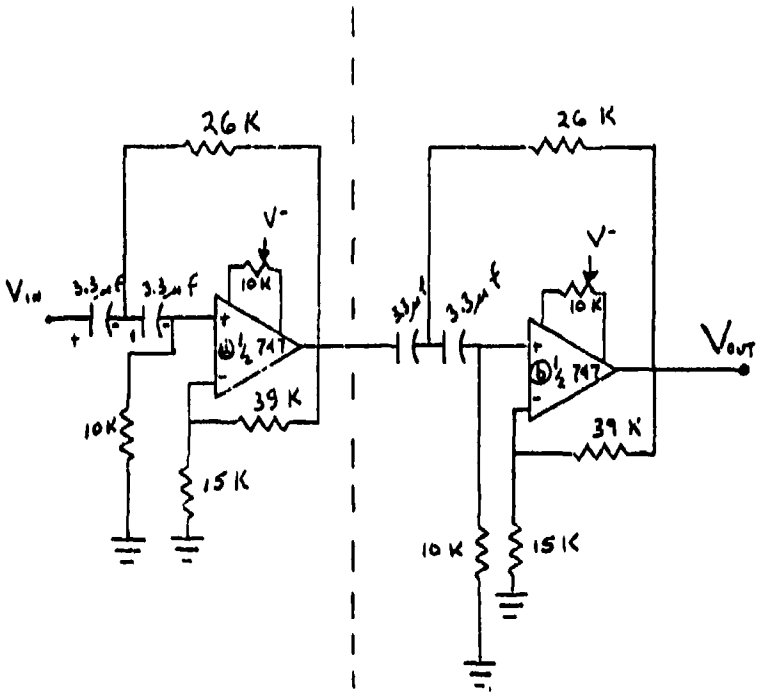

Figure 4. High-pass filter stage. A 747 Op-Amp is connected with elements to form a fourth-order high-pass filter with cutoff frequency at 3 Hz.

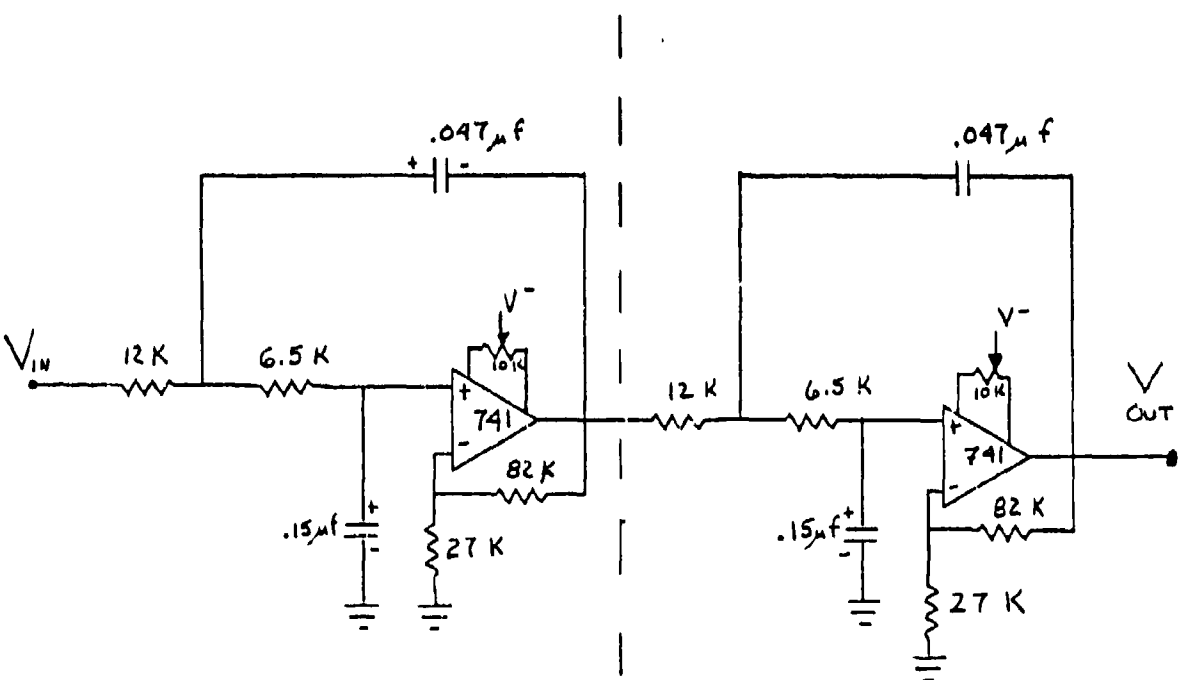

Figure 5. Fourth-order low-pass filter stage. A 747 Op-Amp is connected with elements to form a low-pass filter. The cutoff frequency for the low-pass filter is 200 Hz. The output of this stage can be displayed on an oscilloscope.

High-pass Filter Stage

Two second-order high-pass Butterworth filter networks are cascaded in series to produce a fourth-order VCVS filter. Each second-order network has a gain of 4. The generalized transfer function of a second-order high-pass filter is given as:

$$H_{hp}(s) = \frac{V_{in}(s)}{V_{out}(s)} = \frac{K\,s^2}{s^2 + w_c sa/b + w_c^2/b} \qquad (1)$$

Where: K is the network gain=4,
a & b are the normalized low-pass Butterworth filter coefficients, and
w_c is the cutoff frequency in radians per second.

Values for the capacitors and resistors are computed by the following equations:

$$C = 10/f_c\ \mu F = 3.3\ \mu F \qquad (2)$$

$$R_1 = \frac{4b}{[a + \sqrt{a^2 + 8b(K-1)}]w_c C} = 10K \text{ ohms} \qquad (3)$$

$$R_2 = b/(w_c^2 C^2 R_1) = 26.2K \text{ ohms} \qquad (4)$$

$$R_4 = KR_1 = 40K \text{ ohms} \qquad (5)$$

$$R_3 = R_4/(K-1) \text{ or } = 13.3K \text{ ohms} \quad \text{when } K>1 \qquad (6)$$

The high-pass filter circuit is given in Figure 4. The output of the high-pass filter stage is connected to the input of a low-pass filter with cutoff frequency (f_c) at 200 Hz.

Low-pass Filter Stage

As before, two second-order, low-pass, Butterworth filter networks are cascaded in series to produce a fourth-order, VCVS, low-pass filter stage. Each network has a gain of 4 resulting in a total filter stage gain of 16. The generalized transfer function of a second-order low-pass filter is given as:

$$H_{lp}(s) = \frac{V_{in}(s)}{V_{out}(s)} = \frac{Kbw_c^2}{s^2 + aw_c s + bw_c^2} \qquad (7)$$

Where K is the stage gain (K=4),
a & b are the normalized low-pass Butterworth filter coefficients, and
$W_c = 2pi(f_c)$ is the cutoff frequency in radians per second.

Values for the circuit elements are computed as follows:

$$C_2 \leq 10/f_c = 0.05\ \mu F \tag{8}$$

The closest capacitor value is 0.047 μF.

$$C_1 \leq \frac{[a_2 + 4b(K-1)]C_2}{4b} = 0.15\ \mu F \tag{9}$$

$$R_1 = \frac{2}{[aC_2 + \sqrt{[a^2 + 4b)K-1)]C_2^2 - 4bC_1C_2}]w_c} = 13.4K \text{ ohms} \tag{10}$$

$$R_2 = 1/(bC_1C_2R_1w_c^2) = 6.7K \text{ ohms} \tag{11}$$

$$R_4 = K(R_1 + R_2) = 80.4K \text{ ohms} \tag{12}$$

$$R_3 = R_4/(K-1) = 26.8K \text{ ohms} \quad \text{for } K>1 \tag{13}$$

The low-pass filter circuit is given in Figure 5. The output of this final filter stage is for connection to a monitor or processing system. Tests of the ECG monitoring circuitry are categorized into two types of tests: static and dynamic.

Static Tests

The first step is to zero the operational amplifier circuit from other stages, both inverting and noninverting inputs are grounded and the 10K ohms null-offset potentiometer is adjusted until the amplifier output is zero.

Common-mode Test

To adjust the high CMRR differential amplifier stage, a common signal is applied to the noninverting inputs while the inverting inputs are grounded. Then the 20K ohms potentiometer between the LM0052CD amplifiers 4 and 5 is adjusted to minimize the output of amplifier 6. The common signal is usually set at 60 Hz, since it is the most common undesirable noise.

Dynamic Tests

Once the system static tests are completed, dynamic testing is performed by incorporating the working circuit into the environment for which it was designed. Dry electrodes were placed at the throat with the active electrodes on the side of the neck and the common at the trachea. Results shown in Figures 6(a) and 6(b) indicated a visible ECG (lower trace) with at least a 5-to-1 signal-to-noise ratio. The signal is sufficiently clean for heart-rate monitoring or use of the R-wave for timing reference.

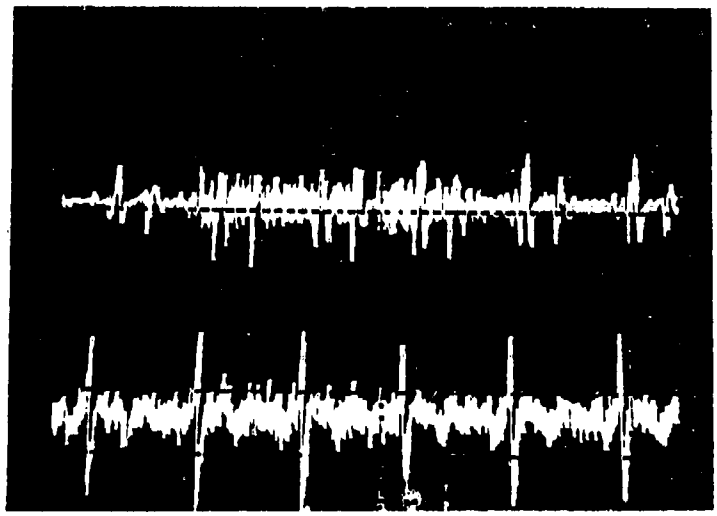

Figure 6a. Output signals recorded from the prototype system show quiet breathing from the electronic stethoscope placed at the trachea. Heart sounds may be seen through the respiration signal. The lower trace is the ECG obtained with the dry electrode system from the area of the neck.

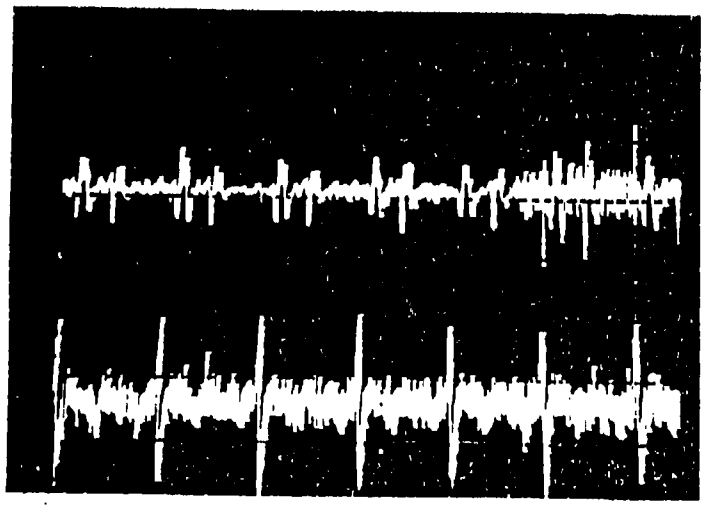

Figure 6b. Continuation of the signals shown in Figure 6b. Note that the heart sounds can be readily seen as the breathing is temporarily held. Vertical scale 0.33 in. = 0.5 V and horizontal scale 0.33 in. = 0.5 s.

SURFACE TEMPERATURE DETECTOR

Basic Theory

The surface temperature of a human tends to be 4 to 8 °F below the core temperature, which is between 95 and 102 °F. This surface temperature difference is largely dependent on the thermal properties of the skin temperature (T_{sk}) which serves to help regulate core temperature. Skin temperature varies as the blood flow is shunted to or away from the skin surface to dissipate or conserve heat, respectively; this is especially significant on the surface of the extremities. Despite the variations, the mean surface temperature rises or falls with corresponding changes in core temperature. Measuring the T_{sk} at the neck appears appropriate when access to the body is limited by a protective garment. The T_{sk} at the neck does not tend to vary appreciably with changes in surface vascularization. This surface vascularization is due to the thinness of the tissue and the lack of heavy vascularization in the neck area. This section discusses the method and describes a circuit by which T_{sk} can be measured, but not the application of the measurements to physiological data interpretation in vital life signs.

Thermistors

A thermistor is a semiconductor resistance temperature detector. The resistance of the bulk material is affected by the temperature to which it is subjected. Generally, there is an inverse relationship between temperature and resistance. In addition, thermistor resistance is affected by the strain applied to the device. This resistance is a source of noise and should be avoided when mounting the transducer. Thermistors are not always linear for large changes in temperature; however, the physiological range for surface temperature is comparatively small and a linear approximation of the resistance to temperature relationship can be considered sufficiently accurate. The resistance to temperature dependence is given by the following relationship:

$$R = R(t_0)e^{C(1/t - 1/t_0)} \qquad (14)$$

R = resistance at temperature t in ohms,
$R(t_0)$ = resistance at temperature t_0 in ohms,
C = material constant,
t, t_0 = temperature in degrees Kelvin.

Thermistors are made in the form of beads, rods, discs, and chips. Materials can be compared as the ratio of resistance at temperature t to the resistance at 298 °K (77 °F).

Circuit Design

The temperature detector circuit consists of a bridge network configured as a null offset detector. The output of the bridge is sensed by a differential amplifier. The amplifier output is fed into a scaling voltage divider to give the value of deviation from the null. The absolute temperature value of the null position is set by a voltage divider with the negative supply as its source. This negative value is subtracted from the positive deflection from null in a differential amplifier to give the temperature output at an amplitude of 10 mV/°F. The output temperature value may be read directly by a voltmeter. The temperature detector circuitry is shown in Figure 7.

Thermistor Probe

The sensing probe used to sense the T_{sk} is a disc thermistor with a diameter of approximately 0.8 in. The thermistor is mounted on a foam block which is hollowed to accept one side of the disc and thermally insulate it from ambient conditions that may interfere when using only one side of the probe to measure temperature. At midrange temperature, 92 °F, the resistance of the thermistor is found to be 82.4 ohms, and the variation with temperature is found to be 2.1 ohms/°F.

Bridge Network

The reference (R_{Ref}) leg of the bridge is chosen to approximate the thermistor resistance at the middle of the appropriate temperature range, 85 to 105 °F. The midvalue, 97 °F, is set at 84 ohms. The 2 fixed resistors (R_3) are chosen to be at least a factor of 10 larger than the value of the reference resistors in order to keep the relative displacement from null small. This displacement factor avoids serious nonlinearity problems associated with large deviations on a bridge. A 1 kilohm resistor is chosen because it is a readily available resistor and it is more than a factor of 10 larger than the reference resistor. The equivalent resistance of the network in the null condition is 542 ohms. The resulting bridge output varies 12.9 mV/°F about midrange.

Differential Amplifier

A differential amplifier is needed to sense the signal that appears across the bridge. An LM741CN is used as the amplifier. In differential operation a common-mode rejection ratio of 60 dBm can be achieved. Any common-mode error will therefore be very small and can be adjusted for with an offset voltage in later circuit stages. Unity gain is used to assure even loading of the bridge. The input resistances (R_1 and R_2) to the amplifier are chosen to be significantly larger than the 540 ohms equivalent bridge source resistance. This resistance is adequate to minimize loading distortion yet remain compatible with the 300K ohms amplifier terminal input resistance.

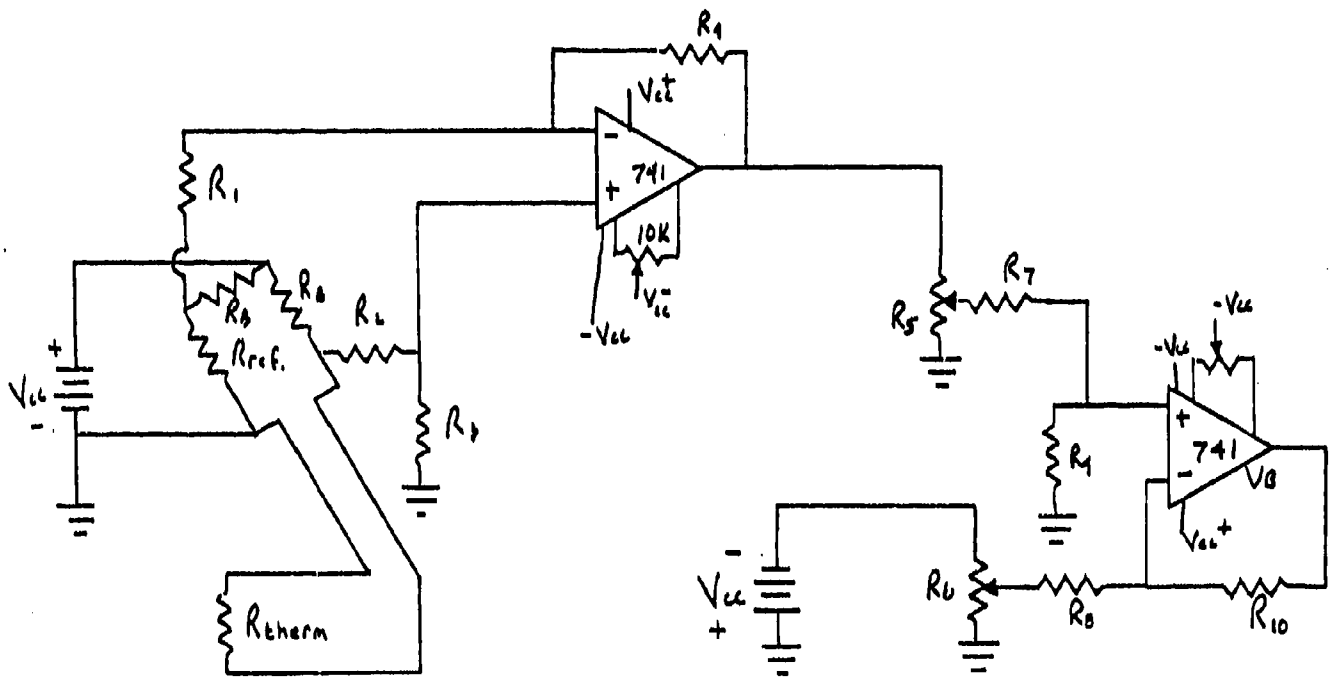

Figure 7. Surface temperature detection circuit. A bridge configuration is scaled and compared with a reference voltage. Standard 741 Op Amps are used in the design.

Scaling Voltage Divider

Scaling voltage divider arrangements are used to adjust the signal to the proper scale before summing. This scales the signal to be 10 mV/°F as a matter of convenience. The ouput of the bridge differential amplifier is input to a 50K ohms trimpot. This method of scaling is used in lieu of varying the bridge amplifier gain since the magnitude of the bridge output at the 9 VDC excitation voltage was larger than required for the summation stage. In addition, voltage division scaling means loading of the bridge by the amplifier remains constant. Also, the offset value of the null temperature is set by a voltage divider , thus, allowing appropriate calibration and adjustment of this parameter.

Summing Differential Amplifier

The final output is obtained by adding the scaled offset voltage to the scaled bridge input. A differential amplifier is used to isolate and sum the two scaled values. Isolation prevents loading of the circuit through the summing junction. The positive value of the scaled bridge output is fed to the noninverting input terminal of the amplifier and the negative scaled offset voltage is fed to the inverting terminal of the amplifier. A second LM741CN is used to form a simple differential amplifier with a common-mode rejection ratio of 60 dBm. Since the input values are scaled by scaling dividers, the amplifier gain is set at unity by using 5K ohms input, feedback, and grounding resistors.

Calibration

As the standard for calibration, a Marshall Electronics "Astrotemp 9" electronic digital thermometer was used in a water bath. The water bath was arranged with a Fisher "Thermix" stirring hot plate (Model 210T), a standard ring stand with clamps, and a metal beaker. The source voltage was selected to be +/-9 VDC, the voltage from a standard type battery. All voltages and resistances were read with a Tektronixs (Model DM 502A) autoranging digital multimeter.

First, the midpoint of the intended range was maintained in the water bath. The temperature was set at 94 °F. The resistance of the probe was read. This value was approximately 82 ohms. The reference resistance was chosen to be 84 ohms, a readily obtainable value. The water bath temperature was raised through the range until the bridge output was zero, determining the null to be 92 °F. While the water bath temperature was rising, the output of the bridge was monitored, determining the bridge sensitivity. The sensitivity was found to be 12.9 mV/°F.

Second, the differential amplifier for the bridge (LM741CN) was adjusted for null offset. Prior to connecting the amplifier, both bridge inputs were grounded and the output was adjusted for zero volts DC.

Third, the voltage divider for the differential output was set by varying the water bath temperature and adjusting the output to the desired

scaling. The output was set for a scaling factor of 10 mV/°F on a 50K ohms trimpot.

Fourth, the voltage divider for the null temperature output was set by adjusting the wiper until the appropriately scaled value of the null appeared. The scaling was set at 1 mV/°F to match the scaled differential output from the bridge. The null temperature of 92.0 °F resulted in a 920 mV output from a 10K ohms trimpot.

Fifth, the differential summing amplifier (LM741CN) was adjusted for DC null offset. Prior to connecting the amplifier to the scaling voltage dividers, the inputs to the amplifier were grounded and the null offset adjusted for a zero volt DC output.

The circuit output, in units of 10 mV/°F, was recorded as a function of temperature. The temperature of the water bath was raised through the sensing range. Temperature data from both the circuit and the Astrotemp 9 unit were collected and plotted as shown in Figure 8.

The circuit with the thermistor probe is linear over the range of 90-102 °F. A different thermistor could be tested with this same circuit design. The reference resistance could be changed to a midrange value using the steps previously outlined. The sensitivity and the null temperature would also need to be calibrated as previously outlined. A variable null temperature can be achieved through the use of an appropriately sized potentiometer in place of the reference resistance. Calibration would need to be performed.

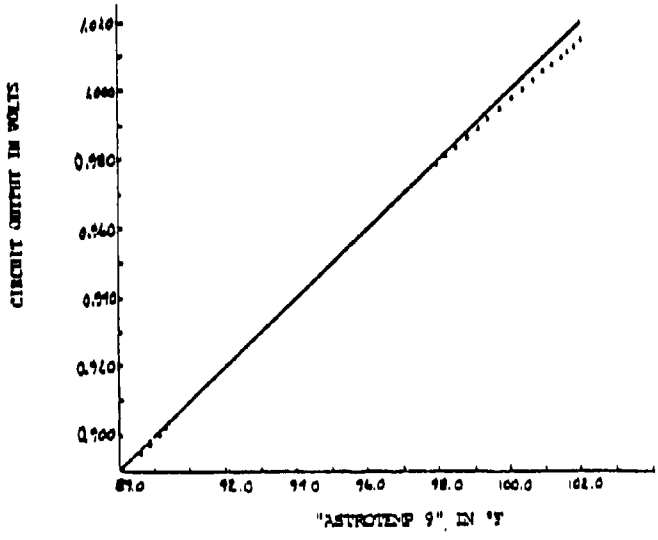

Figure 8. Comparison of temperature detector to Astrotemp 9 unit. Linearity is 1 up to 99°F.

RECOMMENDED MODIFICATIONS

The original task had been envisioned as the fabrication of an array of sensing elements which were to be connected to some unknown circuitry yet to be designed. In an effort to provide some engineering specifications to the follow-on system, the yet to be designed system was developed with standard easily available commercial electronics components. The system works better than envisioned, but it needs to be modified before it may be considered in any operational study.

The modifications may take several courses and thus will require some management decisions. First, the sensors should be miniaturized, especially the electronic stethoscope. The electronic stethoscope could be divided into two parts: the condenser microphone and the signal conditioning circuitry. Modification of the suit would be required if the button size microphone was attached to the inside of the protective garment with some type of connection on the outer side. The signal conditioning circuits could be enclosed in some hand-held container. Since the output of the prototype is to an oscilloscope, additional signal processing circuitry must be designed and added to the device so that the operator can read heart rate or respiration rate on a digital display. This modification is an addition to the system. The entire signal conditioning, processing, and displaying unit should be miniaturized to the size of a hand-held calculator.

Another recommended modification is to the dry electrode/ECG system. Consideration should be given to embedding the dry electrodes to the inside of the suit. Connections from the electrodes to a single location, multiple input/output jack must be incorporated into the suit. Again, the signal conditioning, processing, and displaying circuit units should be miniaturized and enclosed in a calculator size container.

In summary, the three dry electrodes, the condensor microphone, and the small thermistor sensor could be incorporated as part of the protective garment. If modification to the suit is not advisable, then a small collar of sensor array should be considered. In this case, a method of connecting the collar through the suit to a separate hand-held electronic unit should also be considered.

It is highly recommended that the U.S. Air Force pursue miniaturization of the vital life signs detector system. Consideration should be given to schemes which could derive both heart rate and respiration rate from one sensor, i.e., respiratory sound and heart sound from the electronic stethoscope or heart rate and sinus arrhythmia for respiration rate from the ECG signal with the dry electrode system.

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