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PRINCIPAL INVESTIGATOR: Michael V. Scanlon

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Adelphi, Maryland 20783-1197

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The Army Research Laboratory has developed an acoustic sensor that couples extremely well with the human body to detect and monitor heartbeat and lung sounds. A hand-held version of the sensing pad was configured that can be attached to a field medic's hand or glove for combat casualty care. The configuration allows auscultation through headphones by placement of the medic's hand on the torso or limb. Data collected with a palm-sized sensor demonstrate excellent sensitivity, and Fourier analysis clearly demonstrates heartbeat and breath signatures. The sensing pad consists of a fluid-filled bladder that acts as a fluid extension of the body, forming an acoustical conduit to a sensitive hydrophone within the bladder that detects body sounds. The excellent acoustic coupling between a human body, which is mostly water, and a fluid filled sensor pad enables the collection of high-SNR physiological signatures. The choice of a polychloroprene rubber bladder material with an aquacious gel filler optimizes the acoustic impedance matching, because of the similar sound speeds and densities of the pad and skin materials. Airborne acoustic signals, such as ambient noise, do not couple well to the pad because of significant impedance mismatches and noise-canceling materials.

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Michael V. [signature] 10/17/96

PI - Signature Date

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Abstract

The Army Research Laboratory has developed an acoustic sensor that couples extremely well with the human body to detect and monitor heartbeat and lung sounds. A hand-held version of the sensing pad was configured that can be attached to a field medic's hand or glove for combat casualty care. This configuration allows auscultation through headphones by placement of the medic's hand on the torso or limb. Data collected with a palm-sized sensor demonstrate excellent sensitivity, and Fourier analysis clearly demonstrates heartbeat and breath signatures. The sensing pad consists of a fluid-filled bladder that acts as a fluid extension of the body, forming an acoustical conduit to a sensitive hydrophone within the bladder that detects body sounds. The excellent acoustic coupling between a human body, which is mostly water, and a fluid-filled sensor pad enables the collection of high-SNR physiological signatures. The choice of a polychloroprene rubber bladder material with an aquacious gel filler optimizes the acoustic impedance matching, because of the similar sound speeds and densities of the pad and skin materials. Airborne acoustic signals, such as ambient noise, do not couple well to the pad because of significant impedance mismatches and noise-canceling materials.

1. Introduction

A monitoring pad has been developed that acoustically couples to the human body and gathers physiological acoustic data that propagate into the pad. For combat casualty care, the pad could be an accessory to the Life Support Trauma and Transport (LSTAT) system; attached to an evacuation litter, gurney, or operating table; or simply placed on a person's torso to monitor body sounds before, during, and after injury. When the sensor pad is placed in contact with a patient's thorax, immediate and continuous hands-free monitoring of sounds can aid in the assessment and treatment of cardiac and respiratory function. This is accomplished with passive acoustics, without the need to attach electrodes or other sensors that require accurate placement or clean flesh.

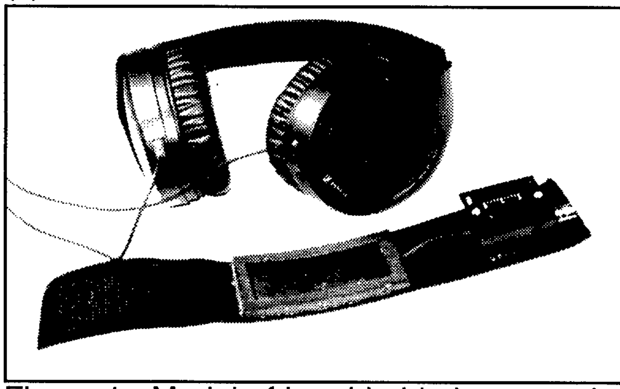
Acoustic analysis can provide amplitude, phase, frequency, duration, rate, and correlative information that may be useful for medical diagnosis, patient care, and research. Aural interpretation of the sensor output is similar to normal auscultation methods employed with standard stethoscopes. Acoustic signal processing and signature analysis may help indicate cessation of breathing or heartbeat, fluid in the lungs, a collapsed lung, an obstructed airway, or an irregular heartbeat.

2. Program

2.1 Formulation

The Army Research Laboratory (ARL) originally proposed to fabricate a torso-sized prototype acoustic sensor pad to be used by the sponsor for testing and evaluation on the LSTAT. Shortly after the program began, of the effort was changed by the sponsor to fabrication of a glove-mounted sensor for a medic to use inside a helicopter, in anticipation of medical evacuation of soldiers injured in Bosnia. Such a hand-held version of the ARL sensor pad could replace the traditional stethoscope; it could be part of a glove for accessibility and ease of use, or could be an attachment to the hand or gloved hand. A nonworking model is shown in figure 1. The flexible and conformal nature of the liquid-filled bladder, acoustic insulation material, and strap makes such a device ideally suited for comfortable body coupling.

(a) (b)



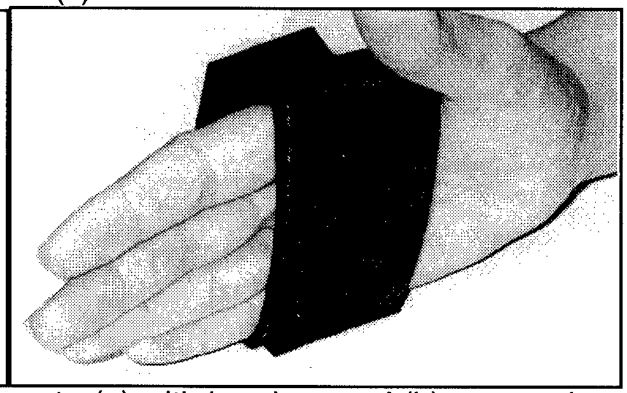


Figure 1: Model of hand-held glove attachment: (a) with headset, and (b) mounted on hand with sensing diaphragm shown.

2.2 Description

ARL was funded to build a sensing pad that could be configured as an attachment to the user's hand or glove, for the purpose of data collection by the sponsor. The dimensions and orientation of the glove-mounted sensor pad were based on the available area, human-factors issues, noninterference with other hardware, and medical techniques used to by the medic to maximize the acoustical contact with the subject. Once the device was assembled, limited testing was conducted at ARL to verify performance. Acoustic monitoring hardware was delivered and demonstrated to the sponsor.

3. Sensor Pad

3.1 Operation

The sensor pad consists of a fluid-filled bladder and a hydrophone. The pad acts as a fluid extension of the body, forming an acoustical conduit to a hydrophone within the bladder that detects body sounds. The bladder is made from a rubber material that is acoustically transparent when in contact with a fluid of similar properties. The excellent acoustic coupling between a human body, which is mostly water, and a fluid-filled sensor pad enables collection of high signal-to-noise ratio heartbeat, breath, and other physiological signatures. The hydrophone coupling to the body through the fluid-filled pad eliminates the body/air interface losses that result when a standard stethoscope's bell is in contact with the skin, as well as various acoustic impedance mismatches and sound transmission effects within the stethoscope's tube as the sounds travel to the ears [1].

3.2 Material Selection

The bladder containing the hydrophone was fabricated out of a polychloroprene rubber, a material used on Navy sonar sensor arrays, which is acoustically transparent when submerged in water. This material, nicknamed "rho-c" rubber, has the same density (ρ) and sound-speed (*c*) as water, and allows sounds to travel through it just as it does through the contacting fluid. This polychloroprene material, or one with similar acoustic properties, will enhance the acoustic coupling between the body and the fluid in the pad by reducing acoustic impedance mismatches.

The fluid in the pad will also have rho-c properties similar to that of the pad material and human flesh to match total system impedence. From ultrasonic propagation studies of tissues at 1 MHz, skin has an average specific acoustic impedence of 1.56 Mrayl, a density of 1.02 g/cm^3, and a sound speed of 1520 to 1580 m/s [2]. As an example of a comparable substitute, urethane rubber "Ecothane CPC-41" has a specific impedence of 1.54 Mrayl, a density of 1.01 g/cm^3, and a sound velocity of 1520 m/s [3].

Water is a convenient fluid to use within the pad since it has suitable rho-c characteristics (1462 m/s and 1.00 g/cm^3); it was used in most of the testing. Sea water more closely matches the body's acoustic transmission properties, since it has a sound speed of 1490 m/s and a density of 1.025 g/cm^3 [4]. The optimal fluid would most likely be a higher viscosity hydrogel, which would limit motion-induced fluid movement that could be transduced by the sensor as acoustic signals. Thick hydrogels or ultrasonic-conduction gels have been perfected for ultrasonic sensor coupling to the skin for monitoring or imaging. Other fluids needing further evaluation include saline, silicone, and certain types of oils.

The sensor housing offers some impedence "mismatch" to prevent airborne noises from coupling to the sensing fluid. Because of a much greater acoustic impedence, sounds will not transmit easily into the housing or sensing fluid. Additional sound insulation material will likely be used to minimize acoustic coupling between the user's hand and the back of the sensor, as well as airborne noises impinging on the sensor. such materials as lead sheets and foam structures provide excellent acoustic attenuation. There are also newer and more effective sound-deadening materials developed for noise reduction within vehicles and submarines that could provide sound attenuation and minimize contact coupling.

3.3 Additional Technical Features

It is important to point out that the sensor pad does more than merely detect the occurrence of a heartbeat or breath, but provides intricate acoustic features of each heart and breath sound. In contrast, the blood pulse oxymeter, for example, provides indication only that a heartbeat has occurred, based on the optical properties of blood flowing into and out of the finger capillaries. It does not provide any indication of quality of heartbeat, breathing status, or stress levels, and has significant difficulties in very cold environments or hypothermia cases, where blood flowing to the extremities is reduced.

The sensor is calibratable, so that amplitudes of various conditions can be accurately observed over time, or compared to those of other patients. The ability to calibrate data means that the sensor's usefulness does not rely on the listener's hearing abilities or acoustic ambient conditions (background noise). In fact, sounds below the typical 20-Hz limit of normal hearing cannot be detected by human ears anyway, but a hydrophone with infrasonic response can detect these signals. Broad-band signals may be used to aid in diagnosis and compared to a data base of signatures or to past experience, either locally or remotely.

The electrical output of this transducer is filtered, amplified, and transmitted to a headset for immediate interpretation, but could be sent to a remote location for consultation or further analysis. Traditional diagnostic methods such as auscultation and examination of the voltage versus time waveform can be augmented by joint time-/frequency-domain Fourier analysis, neural networks, or wavelet-based techniques.

4. Prototype Design Issues

In choosing the acoustic sensor, I evaluated various hydrophones for sensitivity, durability, ease of mounting, and cost. However, because of the bulk and expense of the hydrophones, I chose as the acoustic sensor a waterproof electret microphone, based on previous experimentation, cost, and availability. The microphone and conditioning amplifier are battery operated, thereby removing chances of electrocution. The output of the amplifier is a standard headphone jack, which connects to a headset. Bladder configuration, fabrication method, internal sensor mounting, electronic connections, and glove attachment mechanisms that reduce vibration and eliminate acoustic coupling to the medic's hand were considered.

The original proof-of-principle device, developed at ARL, was a hot-water bottle with a hydrophone placed inside. This hot-water bottle was 25 X 18 X 2 cm, much larger than anticipated for the palm-of-the-hand device. Further research needs to be conducted to address the effect of sensor contact area and configuration. Figure 2 shows the hand-held prototype (with components disassembled) that was built under this program for testing the coupling achievable from a smaller diaphragm (7.5 cm diameter coupling surface). Data were collected with water as the fluid medium.

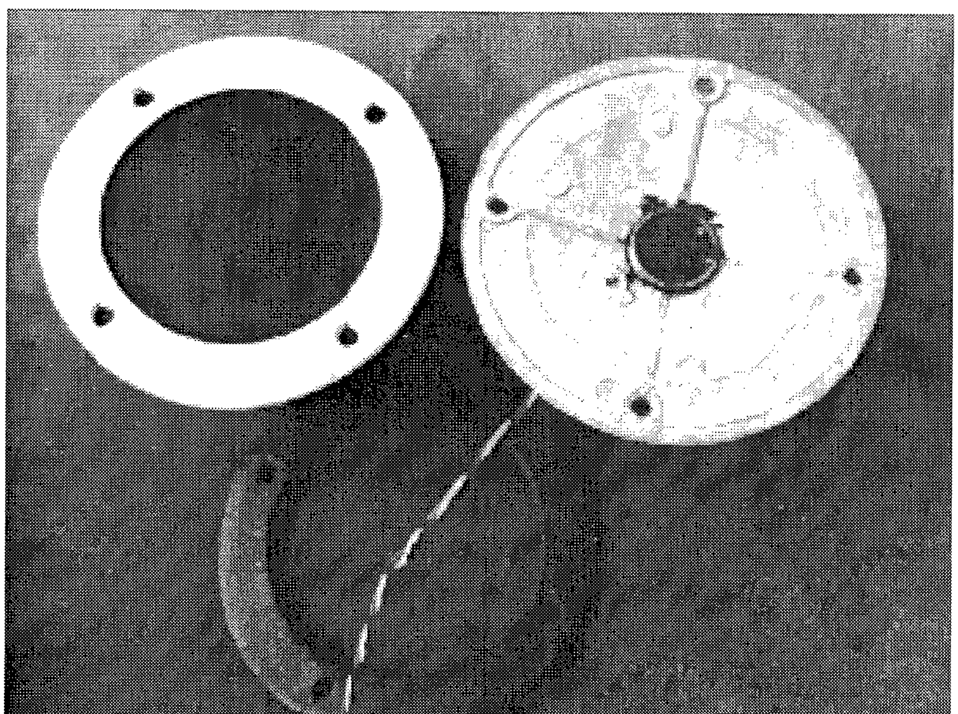


Figure 2: Hand-held sensor disassembled (CW from upper left: body flange with diaphragm, concave housing with microphone, gasket).

When the components are assembled, a fluid chamber is formed between the sensing diaphragm and the inner surfaces of the gasket, housing, and sensor, as seen in the cross-sectional drawing in figure 3. An outer flange forms a sealed chamber by compressing the diaphram and gasket into the housing.

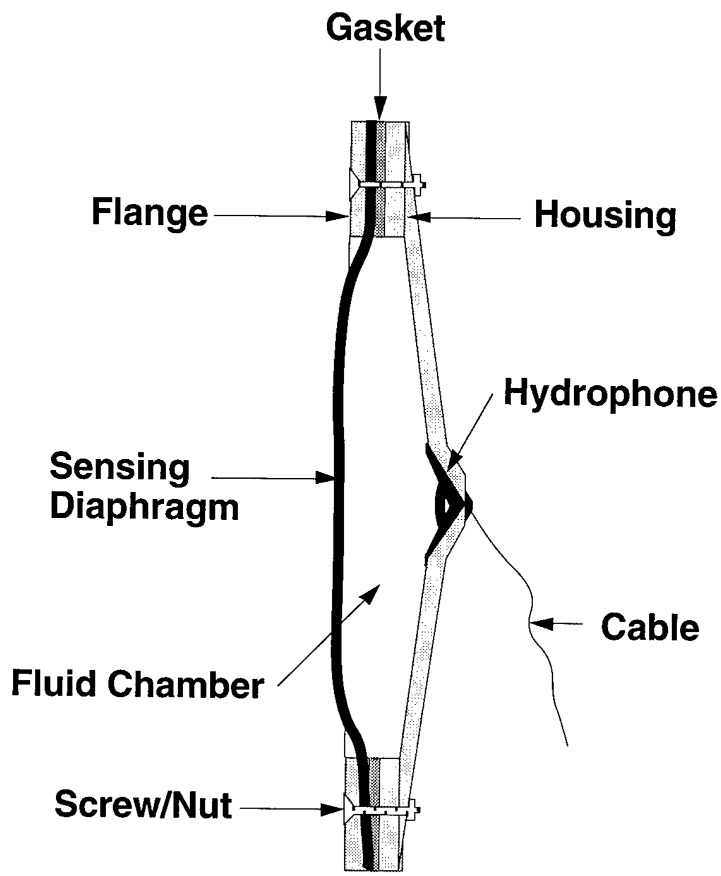


Figure 3. Cross-section view of hand-held sensor.

A waterproofed electret microphone, Knowles model MR-3150, was used as the acoustic sensor. A problem encountered during the program was that the Knowles MR-3150 was not rated for continuous submersion. Because of the limited scope of this development and the low cost of the Knowles MR-3150, it was nevertheless used for data collection and proved to be an effective transducer. Several of the microphones failed after long-term submersion (weeks and sometimes months) because of water condensing within the electret itself. The microphones were replaced with similar kinds for further testing. Microphone specifications, frequency response, and dimensions are given in appendix A. This is obviously not the microphone to be used for long-term measurements, and a suitable hydrophone must be chosen. Appendix B contains a schematic of the amplifier and filter circuitry used for testing the sensor.

Since this was a concept development effort, minimal consideration was given to designing a fieldable device that meets all the needs of the medic or doctor. Issues needing further study include ambidextrous use, the benefit of one sensor versus stereo, monaural versus biaural versus binaural headsets, location, orientation, and mounting of the sensor on the glove, and adjustability (according to how the user contacts the subject, personal preference, or which specific body location is being examined). Contamination and decontamination were not addressed, nor were advanced noise cancelling technologies or materials.

5. Results of Testing and Data Analysis

Data were collected on an adult male with the sensor pad placed on his torso, the sensor in contact with skin, much like a medic might place his hand on an injured soldier's chest. Heartbeats, breaths, and vocalizations were clearly seen and heard in the data. Through headphones, the dominant sounds in the data are heartbeats, with breathing, throat sounds, digestive sounds, and vocalizations clearly audible at a lower level. The raw sensor data can be postprocessed to provide time-frequency representations, which often indicate spectral components not visible (or heard) in the time versus voltage waveform. Postprocessing of digitally recorded data using joint time-frequency analysis software produced the spectrograms included below.

The processed data shown in figure 4 were collected with the small monitoring pad placed under the torso of an adult male lying on a soft mattress, similar to that which would be employed during medical transport or hospital monitoring.

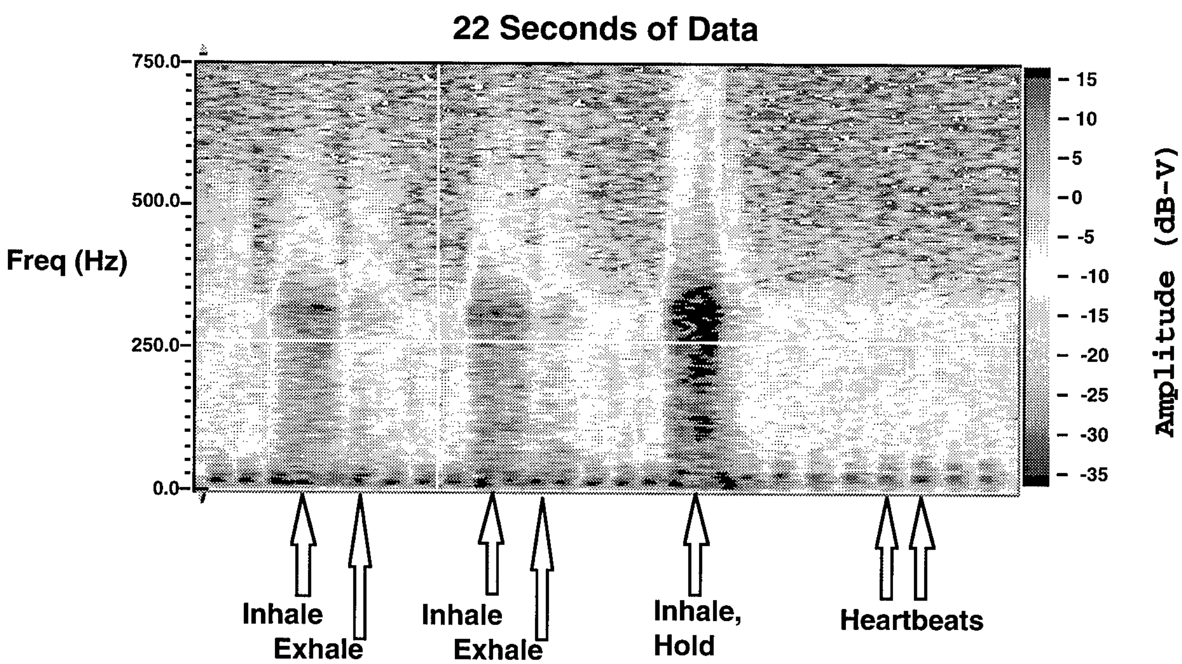


Figure 4. Time-frequency spectrogram of acoustic sensor pad output. An uninjured person lying on sensor, showing 22 seconds of heartbeats, two full breath cycles, and a third breath held without exhaling.

Heartbeats are clearly visible in the 0 to 50 Hz region, and the breaths from 0 to 500 Hz. Note that the inhalation is higher in amplitude than the exhalation for the first two breaths, and that the person takes a much deeper breath the third time in anticipation of holding his breath. This deeper breath contains a much larger bandwidth sound, resulting from an increased flow rate of inhaled air, filling the lungs to a higher capacity. From the high signal-to-noise ratio of the above breath cycles with respect to the background noise, it would be relatively easy to determine if a person had stopped breathing.

Figure 5 shows the time waveform and the spectrogram of several heartbeats and a breath. The sensor's voltage output of figure 5(a) clearly shows that the individual heartbeats contain primarily lower frequency information, whereas the breaths contain more high-frequency, broad-band signals. The spectrogram of figure 5(b) is a frequency representation of the same time waveform data shown in figure 4, and clearly shows the ability to distinguish heartbeats and breaths from background.

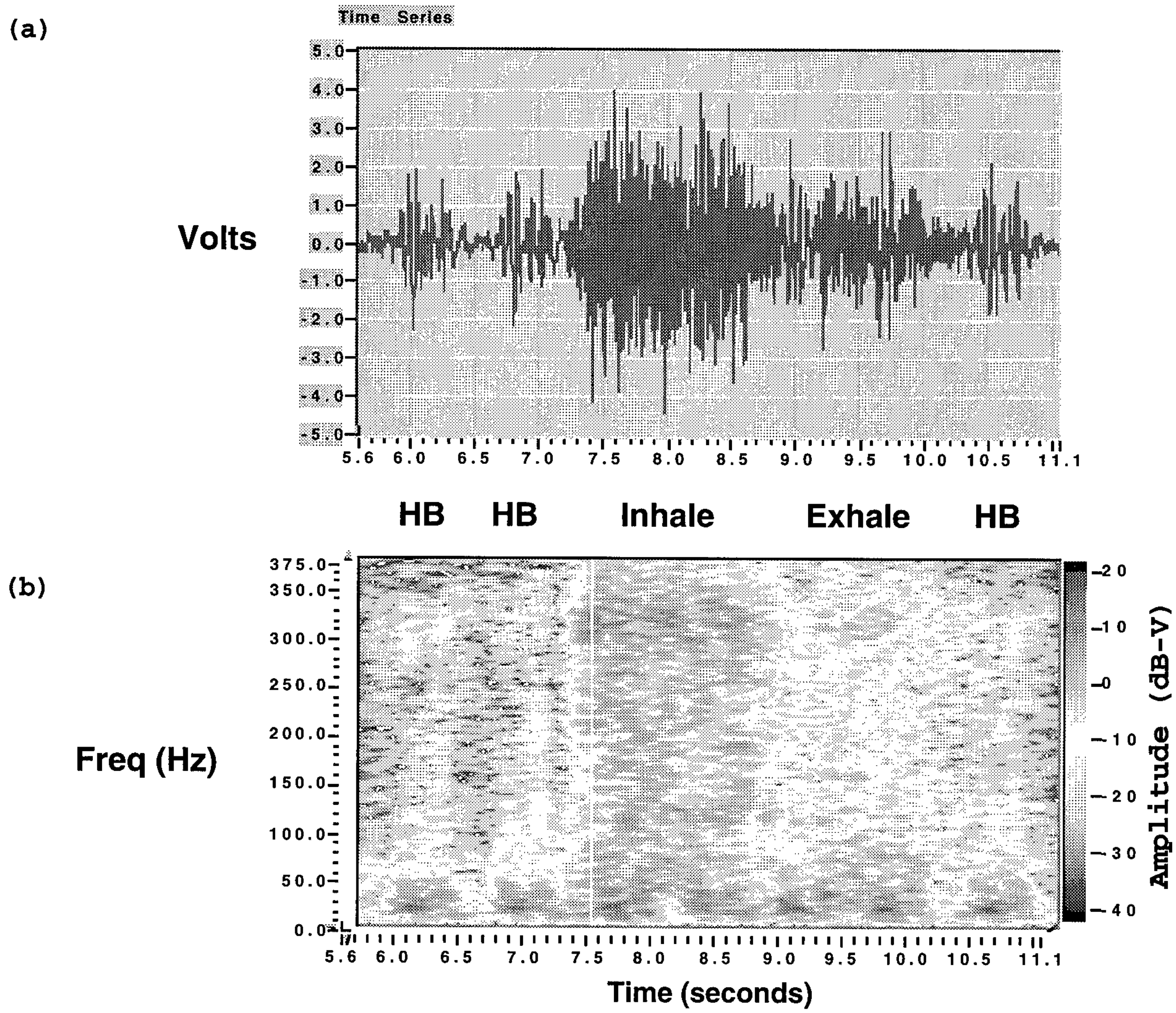


Figure 5. Heartbeat and breath signature: (a) time series and (b) spectrogram of several heartbeats, and a breath cycle.

It can be seen from the above data that the acoustic monitoring pad detects not only the occurrence of heartbeats and breaths, but also the acoustic signature components associated with each event. As was mentioned before, a blood-pulse oxymeter would indicate the occurrence of a heartbeat, but does not give any indication of cardiac performance (amplitude or frequency content) or respiratory function.

To show that the acoustic monitoring pad can detect many differences between individual's heartbeats, data were collected on three adult males who had different heart conditions. The data from these three men were collected with the hand-held acoustic sensor pad placed on the subjects' upper chests while they were seated. Although all the data shown in this paper were taken with the acoustic monitoring pad placed directly in contact with the subject's skin, data have also been collected on an adult and an infant through layers of clothing, indicating that adequate acoustic coupling could be established through an injured soldier's battle dress uniform or other garment. This hand-held "stethoscopic" version of the acoustic sensor pad could be used by field medics, emergency medical technicians, or doctors.

The data represented in figure 6 show the time waveform and spectrogram from a 47-year-old, 180-lb male with a "normal" heartbeat. "Normal" in this case means that he has no known heart condition, and appears to be in good health. These images are included here for comparison to the next two subjects, who have less than normal cardiac function, and to show that heartbeats have distinctive and very repeatable time and frequency distributions.

(a) (b)

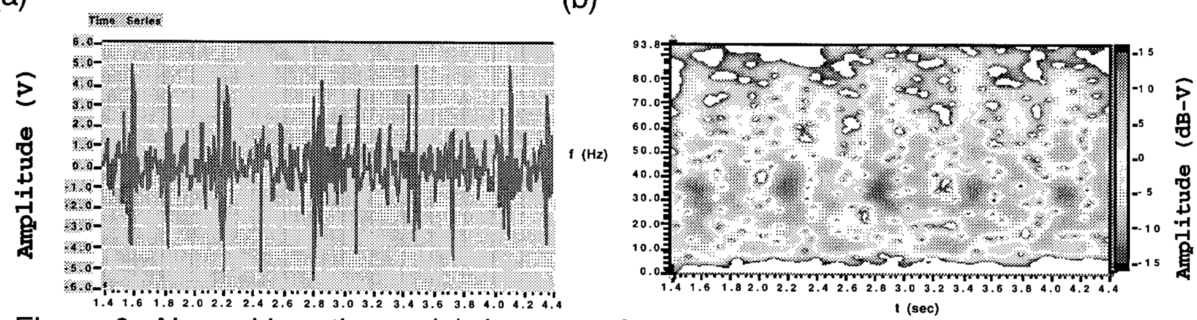


Figure 6. Normal heartbeat: (a) time waveform and (b) spectrogram of an adult male with "normal" heartbeat.

The data in figure 7 show the time waveform and spectrogram from a 32-year-old, 185-lb male with a mild aortic-stenosis heart murmur. This murmur is related to the flapping of the aortic valve between heartsounds, and can acoustically sound like "lub-sh-dub-sh." It can be seen in the spectrogram data of figure 7(b) that there are acoustic components between the first and second heartsounds, and that the separation of events is not as clearly defined as those of the normal heartbeat shown in figure 6(b).

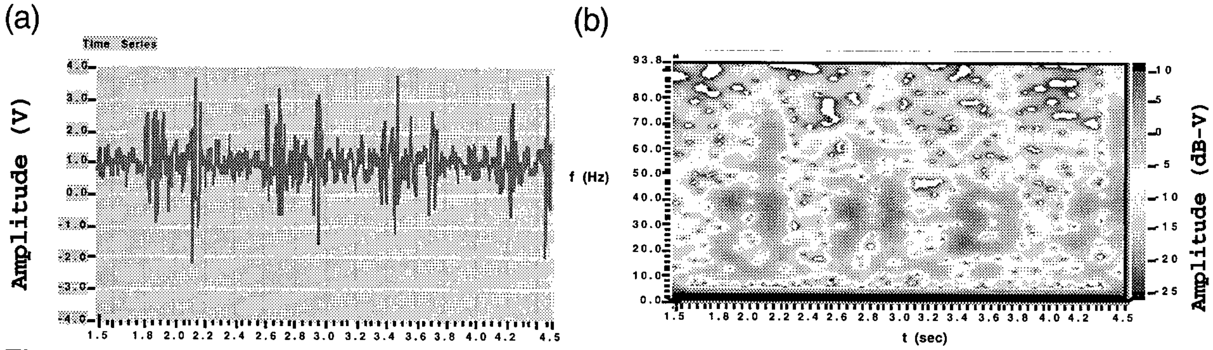


Figure 7. Heart murmur signature: (a) time waveform and (b) spectrogram of an adult male with mild aortic-stenosis heart murmur.

The data in figure 8 are from a 51-year-old, 194-lb male who is on medication to control a condition that causes his heart to periodically skip a beat. The time waveform in figure 8(a) clearly shows the "lub-dub" heartsounds associated with the first and last normal heartbeats, but shows a three-component heart sound preceding the pause where his heart skips a beat. Reviewing all the data from this subject showed that the three-component heartbeat always preceded the missed beats.

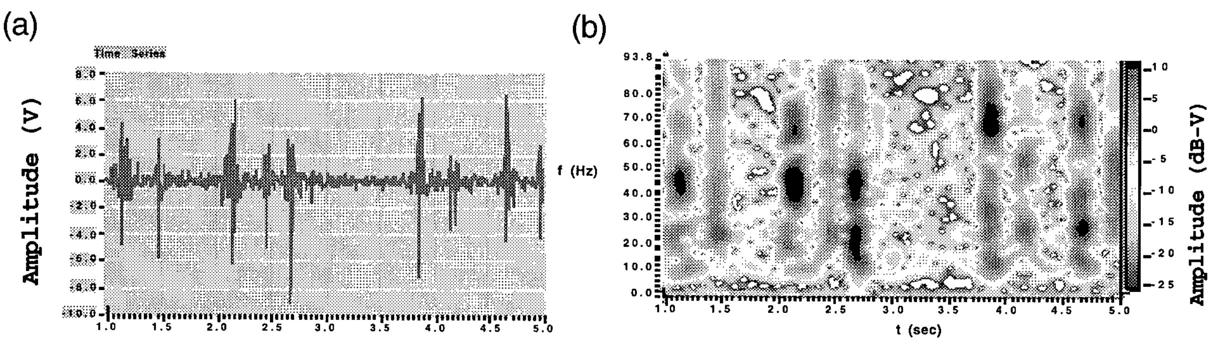


Figure 8. Skipped beat signature: (a) time waveform and (b) spectrogram of a three-component heartsound that precedes a skipped beat. Normal two-component ("lub-dub") heartsounds also visible.

6. Conclusions

The sensor fabricated during this program and the data shown in this final report demonstrate that a high degree of acoustic coupling can be achieved with the hand-held acoustic monitoring pad, and that intricate acoustic details resulting from joint time-frequency analysis can be useful for cardiovascular assessment. The data included in this report clearly show that the absence of breath or the absence of heartbeat is detectable, and that significant spectral detail is contained in the acoustic signature to distinguish certain types of conditions.

7. Recommendations

A prototype sensor should be thoroughly evaluated by the sponsor and potential users for the purpose of verifying signal integrity as compared to the standard stethoscope in various environments, including helicopter and ambulatory transport.

Further funding is needed to develop the science of fluid-filled sensors for physiological sensing. Data should be evaluated with more advanced methods, such as wavelet decomposition and Gabor transform algorithms. Data transmission and soldier interrogation hardware, as well as a hand-held acoustic display for the medic, should also be pursued.

References

1. Peter Lang, "Signal Processing of the First Heart Sound for Cardiac Performance Monitoring," Thesis, Master of Applied Science at the University of Toronto, Department of Electrical and Computer Engineering and the Institute of Biomedical Engineering, 1995.
2. S. A. Goss, R. L. Johnston, and F. Dunn, "Comprehensive Compilation of Empirical Ultrasonic Properties of Mammalian Tissues," J. Acoust. Soc. Amer. **64**, 423-457 (1978).
3. "Acoustic Properties of Rubber," Ultrasonic Devices, Inc. (1996), http://wwak.tn.tudelft.nl/~alexandr/tables/rubbers.html.
4. Sybil P. Parker, Acoustic Source Book, McGraw-Hill (1987), p 8.

Bibliography

1. L. Kinsler, A. Frey, A. Coppens, J. Sanders, *Fundamentals of Acoustics*, 3rd ed., Wiley Press.
2. William S. Burdic, *Underwater Acoustic System Analysis*, Prentice-Hall, (1984).
3. Robert J. Urick, *Principles of Underwater Sound*, 3rd ed., McGraw-Hill, (1983).
4. Robert J. Bobber, *Underwater Electroacoustic Measurements*, Naval Research Laboratory, Department of Navy, (July 1970).
5. Sybil P. Parker, *Fluid Mechanics Source Book*, McGraw-Hill (1987).
6. Glen Ballou, *Handbook for Sound Engineers*, 2nd ed., Macmillan Computer Publishing (1991).
7. Michael V. Scanlon, "*Acoustic Monitoring Pad*," IEEE Engineering in Medicine and Biology Society Conference Proc., and Canadian Medical and Biological Engineering Conference Proceedings, (20-23 September 1995).
8. Michael V. Scanlon, "*Sudden Infant Death Syndrome (SIDS) Monitor and Stimulator*," (14 May 1996), US Patent 5,515,865.
9. Michael V. Scanlon, "*Acoustic Monitoring Pad for Combat Casualty Care*," Advanced Technology Applications for Combat Casualty Care Conference, Fort Walden Beach, Florida, (9 May 1996).
10. Michael V. Scanlon, "*Acoustic Monitoring Pad for Combat Casualty Care*," Army Science Conference, poster presentation, (27 June 1996).

Appendices

Appendix A: Knowles literature (reproduced by permission).
Appendix B: Amplifier schematic.

Appendix A

SUBMERSIBLE WATERPROOF ELECTRET MICROPHONE - MODEL MR-3150
TENTATIVE ENVIRONMENTAL PERFORMANCE

The environmental conditions described below are intended to serve only as a guide. Specific applications require their own test programmes, which cannot be fully reported here.

LIFE
Designed for continuous and intermittent duty for a minimum period of 1 year, under the specified service conditions, or for a reasonable combination of the same.

CONSTRUCTION
The use of passivated, deep draw, stainless steel housings and other corrosive resistant materials, ensures satisfactory operation under any of the environmental service conditions specified in MIL-E-5400 for Class 1 equipment, or any reasonable combination of those conditions, with the following modifications:

TEMPERATURE RANGE (OPERATING)
-40°C to +80°C

TEMPERATURE RANGE (STORAGE)
-60°C to +80°C

ALTITUDE (OPERATIONAL)
Up to 40,000 feet

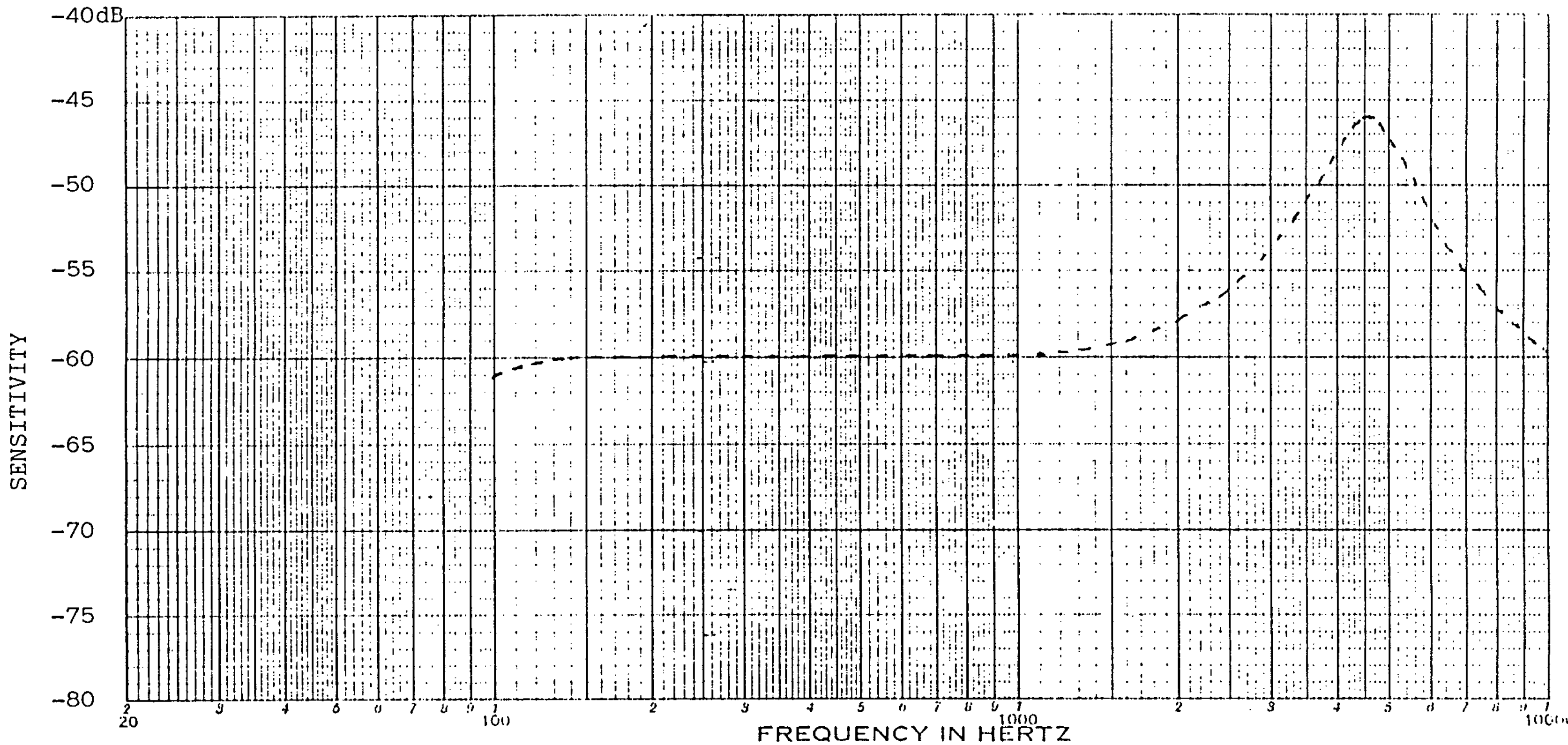
ALTITUDE (NON OPERATIONAL)
Will withstand forces due to explosive decompression from 29.92 inches Hg (sea level) to 5.54 inches Hg (40,000 feet).

IMMERSION
Depth 2 feet, period 24 hours, and depth 50 feet, period 5 minutes, with no resultant loss of performance.

VIBRATION
Curve IV of MIL-E-5400

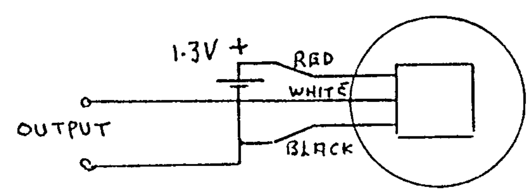
DIFFERENTIAL AIR PRESSURE
Pressure difference between front and back of ±15 PSI shall cause no air leakage.

SUBMERSIBLE WATERPROOF ELECTRET MICROPHONE - MODEL MR-3150
TENTATIVE RESPONSE CURVE

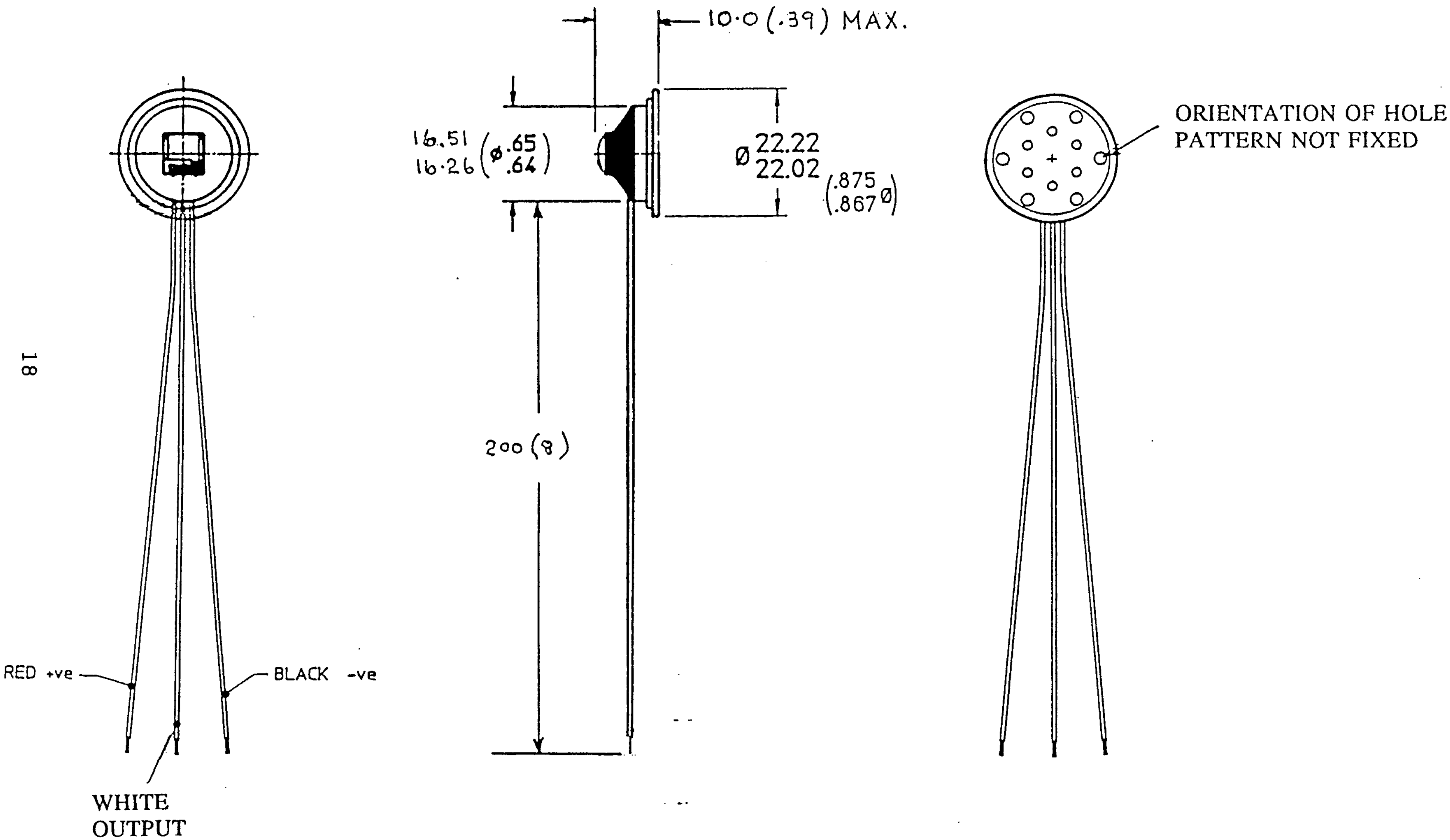


1. OPEN CIRCUIT PRESSURE SENSITIVITY IN dB RELATIVE TO 1.0 VOLT/MICROBAR (0.1 N/m²)
2. DC SUPPLY: 1.3V
3. AMPLIFIER CURRENT DRAIN: 100μA MAX.
4. OUTPUT IMPEDANCE AT 1KHz: 2500 OHMS MAX.
5. CASE CONNECTED TO NEGATIVE TERMINAL
6. "A" WEIGHTED NOISE (1 KHz EQUIVALENT SPL); 31dB SPL MAX.
7. SENSITIVITY / DEVICE CONFORMITY

	FREQUENCY	MIN.	NOM.	MAX.	RANGE OF DEVIATION FROM 1 KHz	
	100	-	-61	-	-4	+2
	1000	-64	-60	-56	-	-
Approx.	4700	-	-47	-	+8	+20



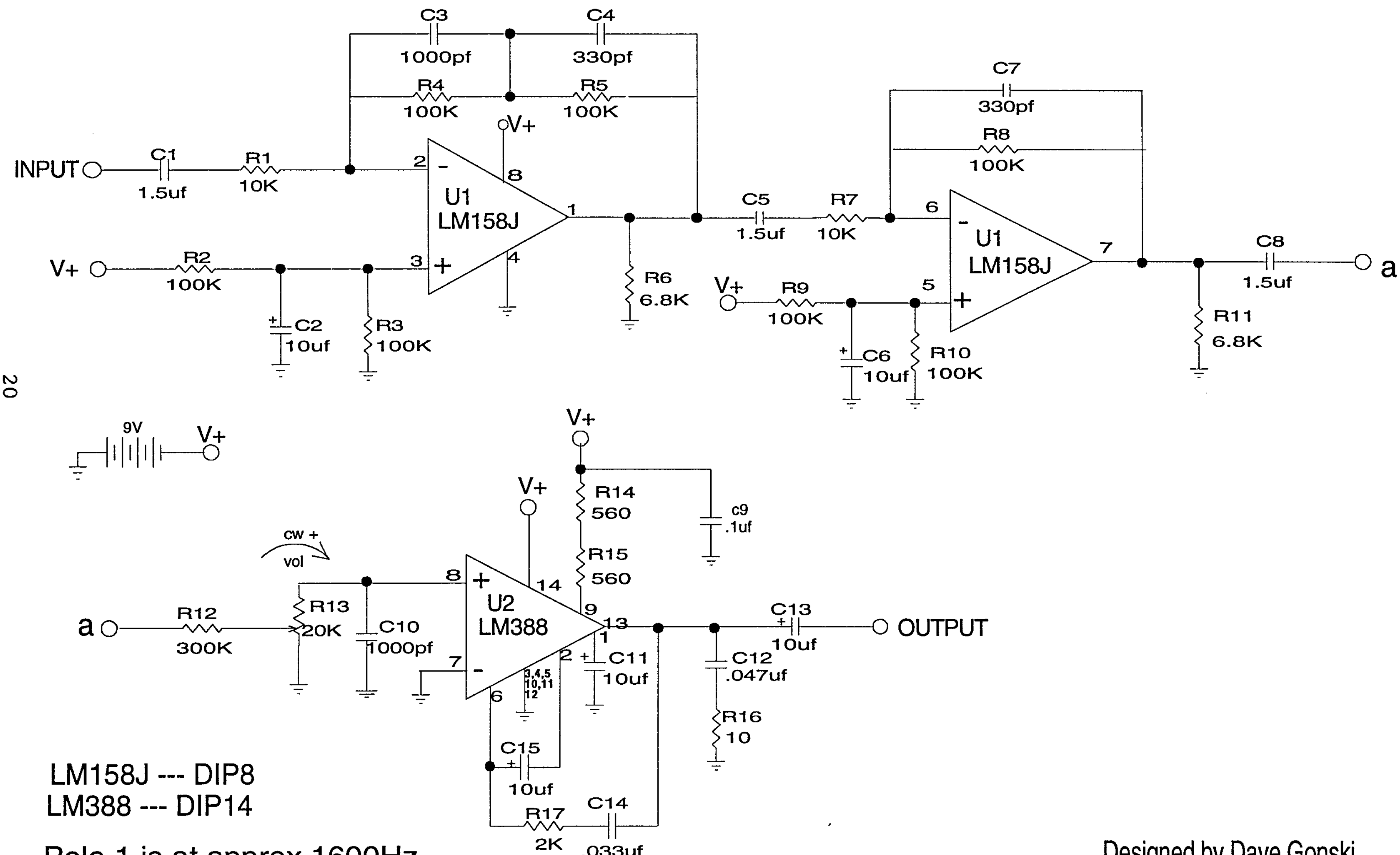
SUBMERSIBLE WATERPROOF ELECTRET MICROPHONE - MODEL MR-3150
TENTATIVE OUTLINE DRAWING



DIMENSIONS IN MILLIMETERS (INCHES)

Appendix B

Sensor Amp & Headphone Driver



LM158J --- DIP8
LM388 --- DIP14

Pole 1 is at approx 1600Hz
Pole 2 is at approx 5kHz

Designed by Dave Gonski
Drawn by Steve Post