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FINAL TECHNICAL REPORT ON ELECTROCARDIOGRAPHIC ELECTRODES FOR RAPID APPLICATION

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FINAL TECHNICAL REPORT
ON
ELECTROCARDIOGRAPHIC ELECTRODES
FOR RAPID APPLICATION

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January 1971

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PREFACE

The technical results presented here represent a ten week effort by its authors during the Summer Institute for Biomedical Research sponsored by the Technology Utilization Office at the Goddard Space Flight Center. Their challenge was to apply NASA developed technology toward the solution of this particular problem and to demonstrate its usefulness to other problems in medical diagnostic monitoring instrumentation.

This report has been published and made available for general use so that others in both the technical and medical communities might benefit from the work of these individuals.

Wayne T. Chen, Coordinator
Summer Institute for Biomedical Research
Technology Utilization Office

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INTRODUCTION

The title of our project and its goal is the development of an electrode for rapid application and a method of rapidly applying the new electrode.

The need for the apparatus to be developed is apparent in both Multitest Screening facilities and Emergency Situations where a 12-lead scalar electrocardiogram would be desired and time is the governing parameter for application. In the multitest screening unit, minutes saved add up in terms of elimination of a possible backlog at the ECG station and an increased number of patients covered per hour. In an emergency situation where a patient may be suffering from a myocardial infarction, it is of the utmost importance to have as complete an assessment of his condition to submit to the doctor so that he may direct proper treatment on the way to the hospital in an attempt to save some of the 60 percent of the heart attack victims that die before getting to the hospital or on arrival because proper treatment could not be given, due to a lack of an adquate diagnosis.

The first part of any research project involves a literature search to find out who has done similar research. In this phase of the project we employed the National Library of Medicine's Computerized Search System, <u>Medlar,</u> and the National Aeronautics and Space Administration's Computerized Search System, <u>Recon</u>.

After the search, at the risk of spreading ourselves too thin, we decided to retain both aspects of our project; i.e., the electrodes and the application. It was at this stage that we fully realized the handicap we would be under with only 10 weeks to complete our full project. Various designs for the electrodes and the harness were discussed, however, only a few of those chosen could be constructed and tested. We tried to carry as many of the ideas as we could to the testing stage, however, at this date we have not yet completed our evaluation.

The goals of the electrode phase of our project is to increase the quality of ECG recordings to the required accuracy for complete analysis. Much research was done to find a method of applying dielectric material to the surface of the electrode. We had to be careful in choosing the dielectric material; a dielectric constant too low – not enough capacitance for electrode to work while a dielectric constant too high – distortion due to aid bubbles or surface discontinuities beneath the electrode. Silver plate copper dishes were used for high conductivity.

In addition to anoidized Tantalum Electrodes we contacted Mr. David Robertson, of Surface Technology, Incorporated in Mountain View, California to tap his resource of knowledge in the area of thin film dielectrics. After much coaxing he agreed to squeeze a few samples of sputtered Quartz (silicon dioxide), and

Tantalum oxide (Ta_2O_5) on a stainless steel substrate for us. As of last night, work had not yet been completed on these samples.

We were able to have silver plated copper disks coated with a 500 Angstrom layer of Silicon Monoxide. This procedure, done in the optical plating laboratory, consists of placing the electrodes substrates in a vacuum chamber and vaporizing silicon monoxide in the same chamber by electrically heating it. The vapors then condense on all available surfaces. The thickness of the coating is time dependent. Also being tested are silver plate electrodes with a silicon monoxide film 1000 Angstroms, the result of the SiO electrode is viewgraph number 8.

From the original viewgraph number 7 standpoint of trying to simply mount an operational amplifier on a standard commercial electrode or on a die cut metal disk we have come a long way.

With our stepping into the area of a capicative coupling with the body we encountered a whole slew of electrical problems. The output impedance of the electrode plate was now quite formidabic. On theoretically the order of 10^{10} olms, it was felt that the operational amplifiers that were available could not reduce this value enough to be acceptable for low resistance transmission.

A Field Effect transistor (FET) was used in a voltage follower configuration to cope with the impedance. In this arrangement (viewgraph) the voltage seen from the source follows that observed at the gate of the FET. The output impedance of the FET is on the order of 4 k olms which is acceptable to present electrocardiograph machines. This design utilized state-of-the-art circuiting.

Although we are not really ready to present a finished, tested and approved final electrode, we do have one prototype silver/SiO_2 electrode complete with circuitry, potteed in a stainless steel cup. The actual final size of the electrode, complete with circuitry, will be much smaller – we plan to eventually use a small integrated circuit chip simply mounted to the electrode disk. It was the time element alone that prevented us from reaching fruition of this phase of the project.

Springs with a constant coefficient of expansion were also considered, but rejected because of their unavailability. Commercially available elastic bandage seemed to be the material best suited for this harness attempt.

July 7, 1970

The purpose of our project, as we see it to date, is (1) to reduce noise, i.e. extraneous signals on EKG recordings and (2) to develop a method for rapid application of the pre-cordial EKG leads. We are attacking the project from four angles: the electrodes, the electrode-skin interface, uses of amplifiers and cables from the electrodes to the machine. At present we have no plans to modify existing EKG machines.

A restriction on the project is that our outputs must be of the same style as present EKG outputs. The low noise level is required since an eventual goal is the digitalization in computer analysis and diagnosis of EKG recordings.

In the area of electrodes we are studying existing models with respect to materials of which they are constructed. We are weighing advantages of those with high conductivity with disadvantages of corrosion and/or polarization in order to find an optimum.

We are planning to carry out a comparison of large electrode surfaces which imply high capacitance and lower impedance to small electrodes which are producing more accurate recordings, but must be positioned more accurately. We also hope to determine whether the shape of the electrode has any effect reference point on the Xiphisternal point and/or on the anterior axial line. These devices must be able to compensate for the chest expansion due to breathing.

The final product of our research should be an integrated system composed of electrodes, amplifiers, cables and an EKG machine with the noise level of the recordings reduced to within the desirable limits.

Studies in the area of electrode-skin interface deals mostly with the impedance seen by the electrode. Possibly, these can be removed through signal amplification. Perspiration, which increases skin conductivity, also presents a difficult problem since this impedance may be changing during the time of our recordings.

A point of present confusion is whether the body can be represented as a resistor or a capacitor, or some combination of these devices, but with two leads of the EKG.

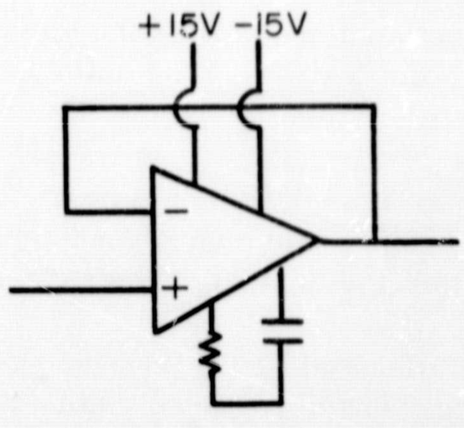
By direct contact electrodes, the impedance has wide variability, not only between patients, but between electrode sites of the same patient. Patient studies also show that the skin-to-electrode implies variability with frequency. One study shows that at a frequency of ten hertz (average frequency for the majority of QRS complexes) impedance variability from zero (±500 ohms) to over 200 K ohms. This variability is at present a large source of error in EKG recordings.

The uses of operational amplifiers to improve the quality of readings is being attempted. A buffer amplifier characterized by a high input impedance and a low output impedance, is to be placed on the actual electrode with the purpose of reducing the impedance in the long-cord (six foot) reading between the electrode and the EKG machine. Thus, lowering the amount of noise picked up in this lead in response to Ohm's Law.

$$V_{noise} = I_{noise} R_{cable}$$

A method must also be found to reduce artifacts due to muscle movement.

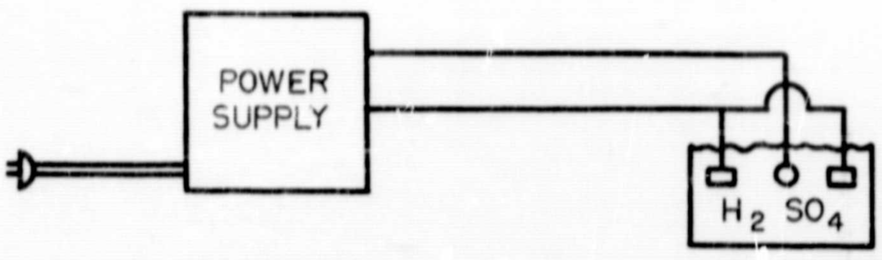
We are also going to attempt the elimination of the right-leg-driven ground, possibly by grounding the amplifier to the forward point supply. This would eliminate the two microVolts to 50 microVolts from this electrode. At present we are testing an operational amplifier of the following circuit design:



Operational Amplifier Circuit Diagram from
EKG Electrode Design Number One

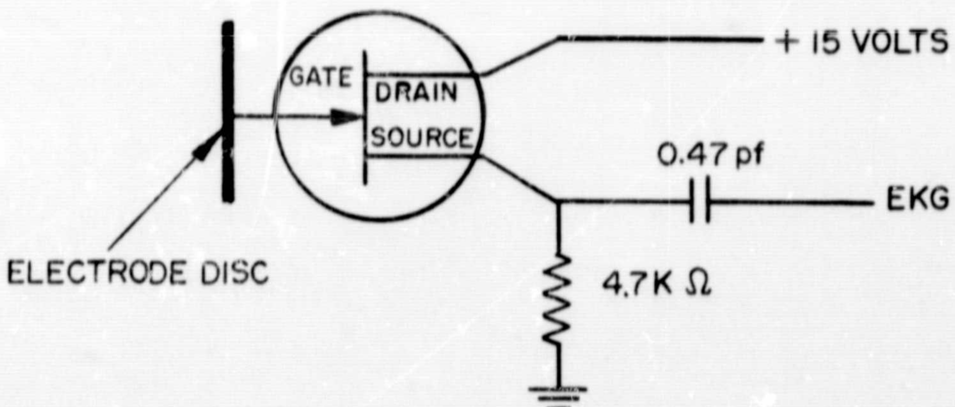
We are using a Burr Brown IC operational amplifier model 3050/01, chosen arbitrarily. We plan to study the operating range of this amplifier reducing the bandwidth to 200 cycles, to determine the offset voltages for up to 500 miliVolts from this electrode. We are also considering the use of other designs employing fet's or mosfet's.

PROCEDURE: Disc to be anodized is placed in .1 molar H_2SO_4, as the anode of the circuit. The cathode is made of the same material as the anode (in this case – both are made of tantalum). An ammeter is placed in the circuit and a power supply capable of supplying 160 volts completes the set up. The voltage is slowly supplied so that the current never exceeds 1 milliamp per square centimeter. When the voltage reaches 160 volts, the circuit is left for an hour. After an hour the power is shut off and the discs are removed and dried.



A Field Effect Transistor (FET) circuit was designed in a standard voltage follower configuration and mounted on the back of the new electrode discs for the purpose of lowering the transmission line impedance and making a low enough output impedance to be acceptable to standard EKG machines.

The circuit is:



On several evenings we rode on the "Heartmobile," a cardiac emergency vehicle sponsored by the Montgomery County Heart Fund. The purpose of these excursions was to explore the applicability of our harness to an emergency situation.

Our conclusion is that our harness can be used in such a situation.

We contacted a Mrs. Mary Beth Lagoey to ride in the heartmobile (Montgomery County Heart Association).

PRECEDING PAGE BLANK NOT FILMED

We questioned the necessity of a 12-lead ECG enroute and decided that the present belt of Landoll's would not be suitable, due to the weight of it. A person having a heart attack would not want the weight on his chest. Another system is necessary for a close electrode skin contact.

Several days were spent testing and trouble shooting our electrodes and circuits. We are also attempting impedance measurements.

Harness:

A Mechanical arm system was considered to be run either manually or by motor. However, time limits caused us to reject this idea.

We tried spraying inflatable bladders out of silicon rubber RTV and Magicvvlc rubber, but both of these attempts led to failures. We sprayed the rubber onto an aluminum mold and removed them after they were dry.

All the bladders exploded upon inflation.

The silicon rubber RTV did not have the desired stretch for our use.

Impedance Circuit

It was found necessary to test impedance somehow at the electrode site for a comparable basis.

The first circuit tried (see Index) was unsuccessful because we were forced to use DC equipment – what was available – Spach's Test, and there is, according to one advisor, an AC capacitance present at the skin.

However, we did manage to use another test: with a Hewlett-Packard Vector Impedance Meter. See Index.

This proved to be very efficient. The only readings we were able to take prior to our presentation are as follows:

	Capacitance @ 3"	Impedance @ 100 Hz
Silver/Silver Chloride Electrodes	.025 uf	2.3 kilohms
Silicon Dioxide Electrodes	.005 uf	1.5 kilohms

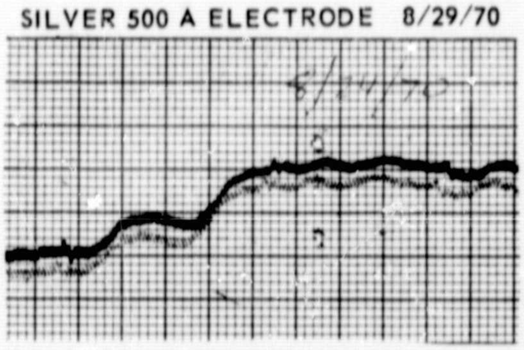
This set up was discovered the day of the presentation.

Further research will be made particularly in comparing impedances on some ohmic electrodes (platinum, silver/silver chloride, silver over stainless steel, etc.) with FET circuits on the back of them.

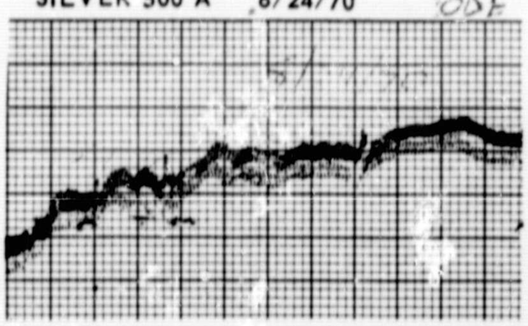
One particularly interesting side light is that we took a GE electrode-disposable (Daisy) and mounted a circuit on the back of this. This electrode was obtained from Miss Siebelt. It retails for $ .70 a piece. A FET can be purchased individually at $ .56 a piece. The cost of our capacitor and resistor are negligible. It is extremely possible to have very soon available commercially, a disposable dry electrode. We are just beginning to test these as well as the others.

The tantalum electrodes and silver electrodes (SiO) are described in the index. The vacuum plating of the SiO, is described here also. The dielectric was 500Å on the SiO_2. Below are comparable readouts of our different EKG electrodes.

SILVER 500 A ELECTRODE 8/29/70



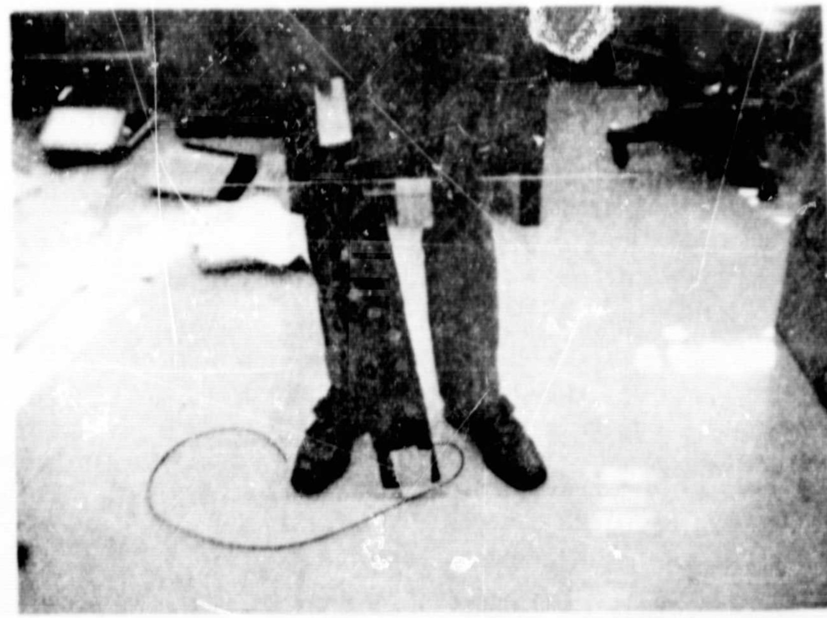
SILVER 500 Å 8/24/70



TANTALUM ELECTRODE 8/25/70

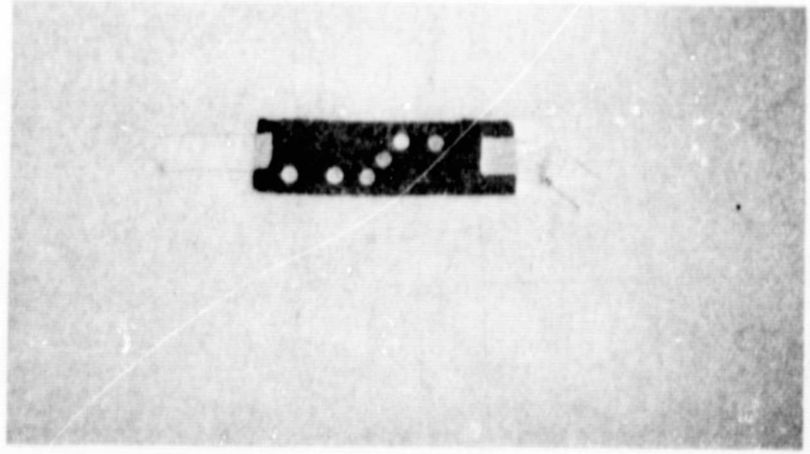
HARNESSES

(See Index for Harness pictures)



The above is a model employing the elastic cloth idea of Landoll's (and approximately his proportional distances). The plexi-glass is just a support mechanism. The ends are fastened with velcro.

This is the copper (beryllium) spring clamped to the chest. Hopefully, we hope to employ an inflatable bladder with imbedded electrodes in it (V_1 and V_2 would be built up). See Index for schematics.



This is an idea that we had for an ambulance situation rapid application belt. It employs elastic cloth and disposable elastic adhesive strips. Its disadvantage is that it needs skin for application. (The patient's clothes must be removed completely in the chest area.)

We have also done research on construction of small, inflatable bladders (latex), but have yet to come up with one strong enough to fit in a harness (cross section) as pictured in the index.

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TASK I
ELECTROCARDIOGRAPHIC ELECTRODES FOR RAPID APPLICATION

COMMENTS

METHODOLOGY

Report written for this project took the form of a narrative in the laboratory notebook. It was not structured to a formal report style, but did have reasonable continuity. The project was identified and the scope of work stated in the introductory section. The results of the NASA literature search were included in the report, but not the actual literature. Goals were stated along with methods of achieving the goals. The experts in the field of medical electrodes were sought out. Their work was reviewed and used to a large extent in the breadboarding of developments in the latest techniques in electrodes. Students were very resourceful in acquiring source material, either through manufacturers, medical facilities and governmental agencies (NBS). The scope of the project was accepted as one input by the students. It was then modified by other inputs during the course of study. Thus, a genuine contribution was made to the task.

RESULTS

This project allowed several solutions in the area of electrodes and electrode application. Several ideas were tried. Although students were not electrical engineers, buffer amplifiers and electrodes were constructed and breadboarded based on guidance of NASA mentor (an instrumentation engineer experienced in amplifier design). Procedures for fabrication of electrodes were noted, including an anodizing procedure of tantalum. They were able to place themselves in an environment of ECG's under various conditions; for example, first-hand experience in the heartmobile, a cardiac emergency vehicle sponsored by the Montgomery County Heart Fund. Interaction between students and NASA was evident. (Measurements for harness were taken on several NASA personnel.) The students' enthusiasm is exhibited by the number of persons contacted and the number of prototype circuits and harnesses fabricated.

CONCLUSION

No formal conclusions were stated. Areas of future work were stated; for example, other belt arrangements, impedance investigation and so on.

Basic concepts of instrumentation and ECG amplifiers were not grasped (not instrumentation engineers). For example, is it necessary to quantify impedance, especially based on the work of others. What are the principles of shielding and grounding and reason for right leg driven ground. Is it necessary to ground the subject. These point out areas which should be emphasized in the formal lectures.

FUTURE APPLICATION/EXPANSION

The technology of dry electrodes and techniques of ECG instrumentation seem to be available. The problem is one of implementing a workable system of instrumentation at a reasonable cost. The Multitest Facility of the Department of Clinical Engineering does provide a 12-lead scaler ECG on one of the test procedures. The instrumentation for this testing station can be improved. Tangled leads, messy electrode paste and sixty cycle noise are the common problems that have existed for many years in electrocardiographic acquisition. Although no harness or electrode was developed, the contribution of the state-of-the-art review will provide the input for the further economical development of dry electrodes with appropriate instrumentation and perhaps a technique for application.