GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: June 1, 1970

Project Title: Development of a Prototype Esophageal Sound Transducer with Control Circuitry

Project No.: A-1258

Project Director: M. E. Sikorski

Sponsor: Emory University

Effective: May 27, 1970 . . . . Estimated to run until: November 30, 1970

Type Agreement: Letter, May 27, 1970 . . . . Amount: $ 5,000

Reports: Monthly Progress Reports
Final Technical Report
(all reports may be letter-type)

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Assigned to . . . . Physical Sciences . . . . Division

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GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT TERMINATION

Date 5/25/71

PROJECT TITLE: Development of a Prototype Esophageal Sound Transducer with Control Circuitry

PROJECT NO: A-1258

PROJECT DIRECTOR: M. H. Sikorski

SPONSOR: Emory University

TERMINATION EFFECTIVE: 5/21/71

CHARGES SHOULD CLEAR ACCOUNTING BY: 5/31/71

Obligations Remaining:

Final Report

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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE of TECHNOLOGY

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November 8, 1971

Dr. E. L. Frederickson
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Subject: Final Report -- Project A-1258
"Development of a Prototype Esophageal Sound Transducer with Control Circuitry"
Georgia Tech Research Institute
27 May, 1970 - 30 November, 1970 ($5,000)

A. Background.

The esophageal auscultation of the heart sounds and murmurs in clinical cases such as, for example, pulmonary emphysema and greatly enlarged heart was recommended as early as at the end of the last century. The importance of recording the heart sounds nearer to the site of origin was then recognized. According to many investigators' experience, the most valuable tracings are recorded at the level of the left atrium, where the atrial sounds and the mitral valve murmurs are louder than over the precordium. It is also agreed that the intrathoracic atrial sound precedes the corresponding precordial sound, the former being due to the atrial contraction itself and not to its effects.

Of interest to the present work is a possible correlation between the various characteristics of heart sounds, as detected in the esophagus, and the depth of anesthesia of the patient. To this end a prototype esophageal sound transducer with control circuitry has been developed at Georgia Tech to allow studies to be made of the effect of various anesthetic drugs on the esophageal heart sounds.

If this approach to objective monitoring of the depth of anesthesia should prove useful, it might serve possibly in combination with other methods, as a basis for the construction of an automatic closed-loop control system for administering optimum amounts of anesthetics during a surgical procedure.

B. Accomplishments.

1. Transducer Development.

The heart sound transducer developed for use in esophageal phonocardiography under the present Contract consists of a 2 mm diameter transistor sensor which is mounted inside and at the tip of a cardiac catheter.

The first version of the esophageal transducer consisted of a 9F woven dacron catheter placed inside of a 12F Dupaco Leffingwell esophageal balloon. The balloon was filled with water to improve the acoustic coupling between the walls of the esophagus and the sensor. Although the system was somewhat cumbersome, good recordings of heart sounds were obtained in the esophagus of several dogs.

The second version of the esophageal sound pickup consisted of a transistor sensor mounted at the end of an 8F polyethylene catheter. In order to provide added mechanical protection for the sensor, a short length of silastic rubber tubing was slipped over the sensor-containing end of the catheter and sealed with Dow-Corning silastic rubber. This catheter proved to be too flexible for easy insertion into the esophagus.

The third and final version of the instrument developed under this Contract consisted of a 9F woven dacron catheter with the sensor placed at the distal end. The mechanical protection for the sensor was provided by a cylindrical sleeve of silver which fitted snugly over the catheter end. A teflon-insulated wire was attached to the metal sleeve, or electrode, and run alongside the catheter to the junction box so that electrocardiogram recordings could be obtained simultaneously with the heart sound data. Since the shape of the P wave in the electrocardiogram (ECG) depends on the position of the electrode with respect to the SA node of the heart, it is possible to standardize the position of the transducer for optimum sound recordings by observing the ECG pattern. It was found that the greatest sound intensity is obtained when the transducer is located 2.5 cm above the point where the P wave starts being biphasic.

Figure 1 shows the frequency response of the esophageal sound transducer. Although the figure shows frequency response down to 10Hz only, the transducer has a flat frequency response all the way down to dc. At 1000 Hz the response is down by 4 db and at 1500 Hz down by 6 db. The -3 db point corresponds approximately to a frequency of 800 Hz.

2. Isolated Control Circuit and System Characteristics.

An isolated control and signal processing circuit has been developed for operating the esophageal sound transducer. Checks in the laboratory showed that leakage currents from the transformer isolated catheter electronics to the case and output circuits are below the recognized 10 microampere safe limit at 115 volts (60 Hertz). A more detailed description of the circuit including diagrams and operating instructions is given in Appendix I.

Figure 2 shows the frequency response of the heart sound amplifier and Figure 3 illustrates the characteristics of the combined transducer-amplifier system. For a sound pressure level of 1 mm Hg (RMS) and mid-frequency amplifier gain of 30 db, the output is -10 dbV $\pm$ 2 db in the frequency range from 16 to 1000 Hz.

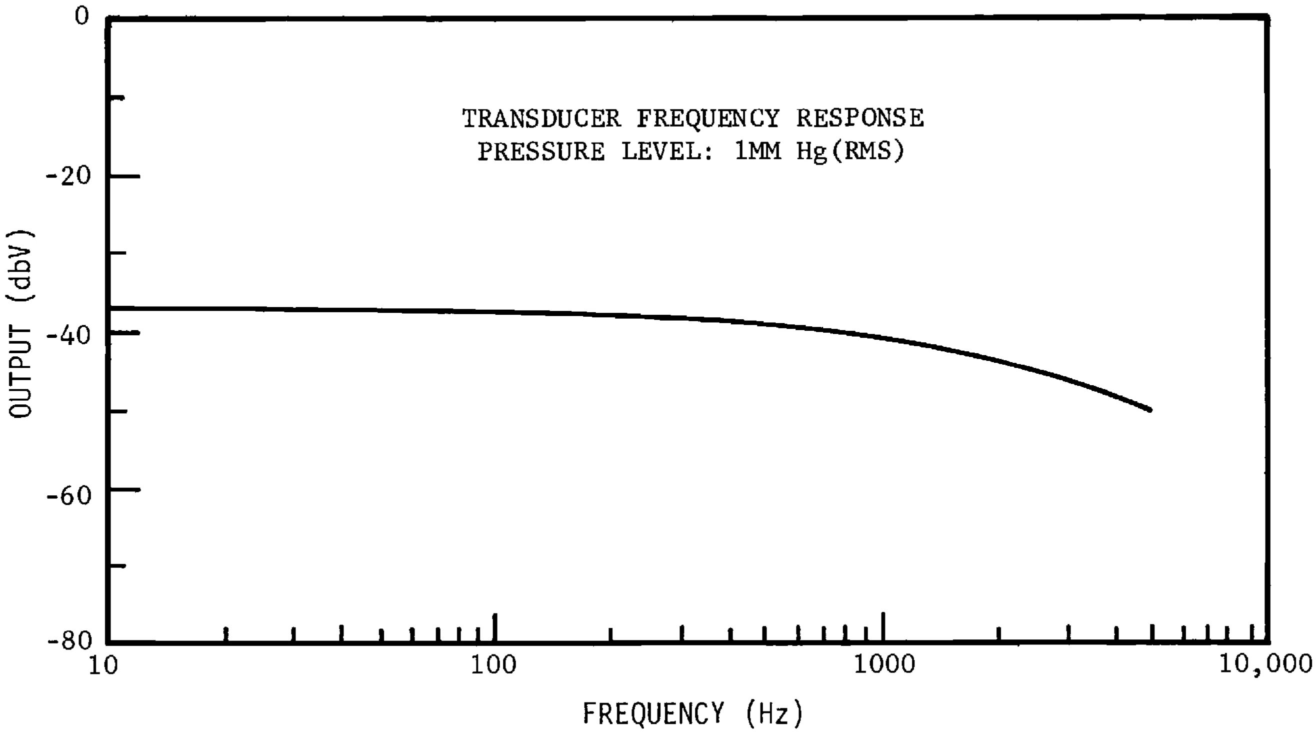

TRANSDUCER FREQUENCY RESPONSE
PRESSURE LEVEL: 1MM Hg(RMS)
0
-20
-40
-60
-80
OUTPUT (dbV)
10
100
1000
10,000
FREQUENCY (Hz)

Figure 1

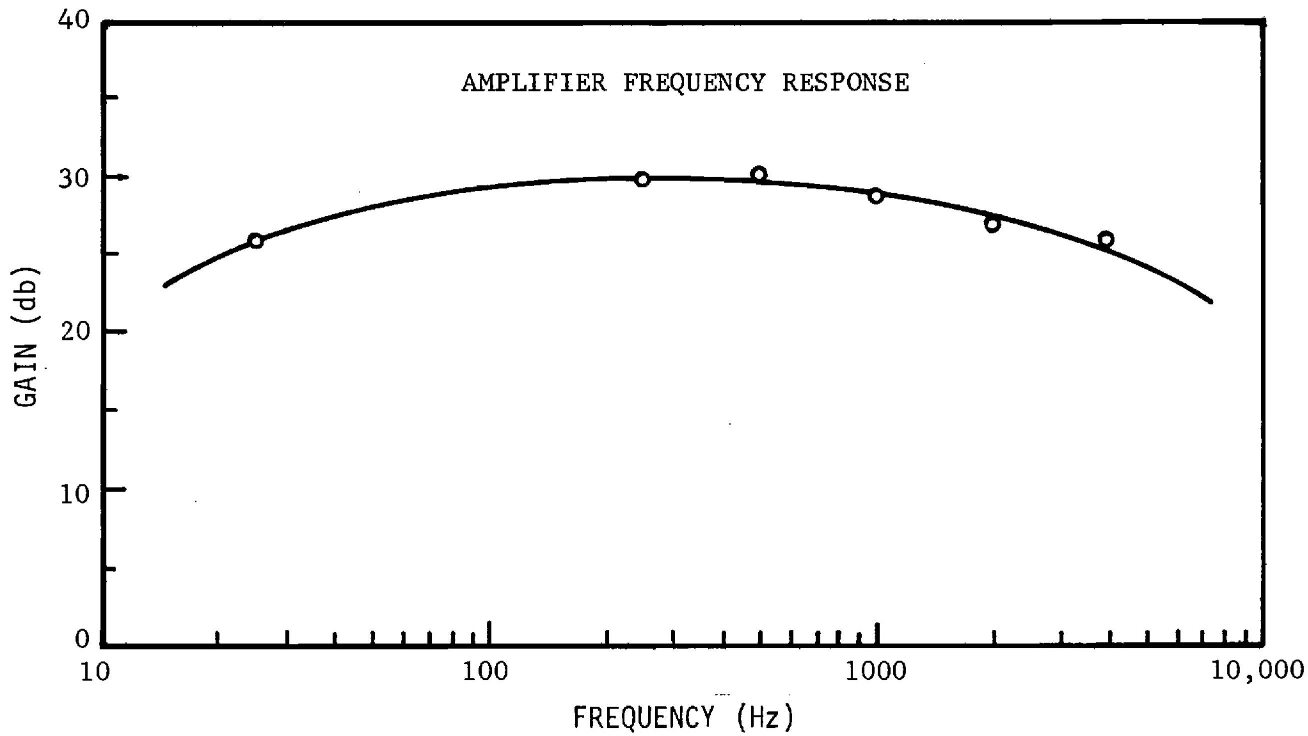

AMPLIFIER FREQUENCY RESPONSE
40
30
20
10
0
GAIN (db)
10
100
1000
10,000
FREQUENCY (Hz)

Figure 2

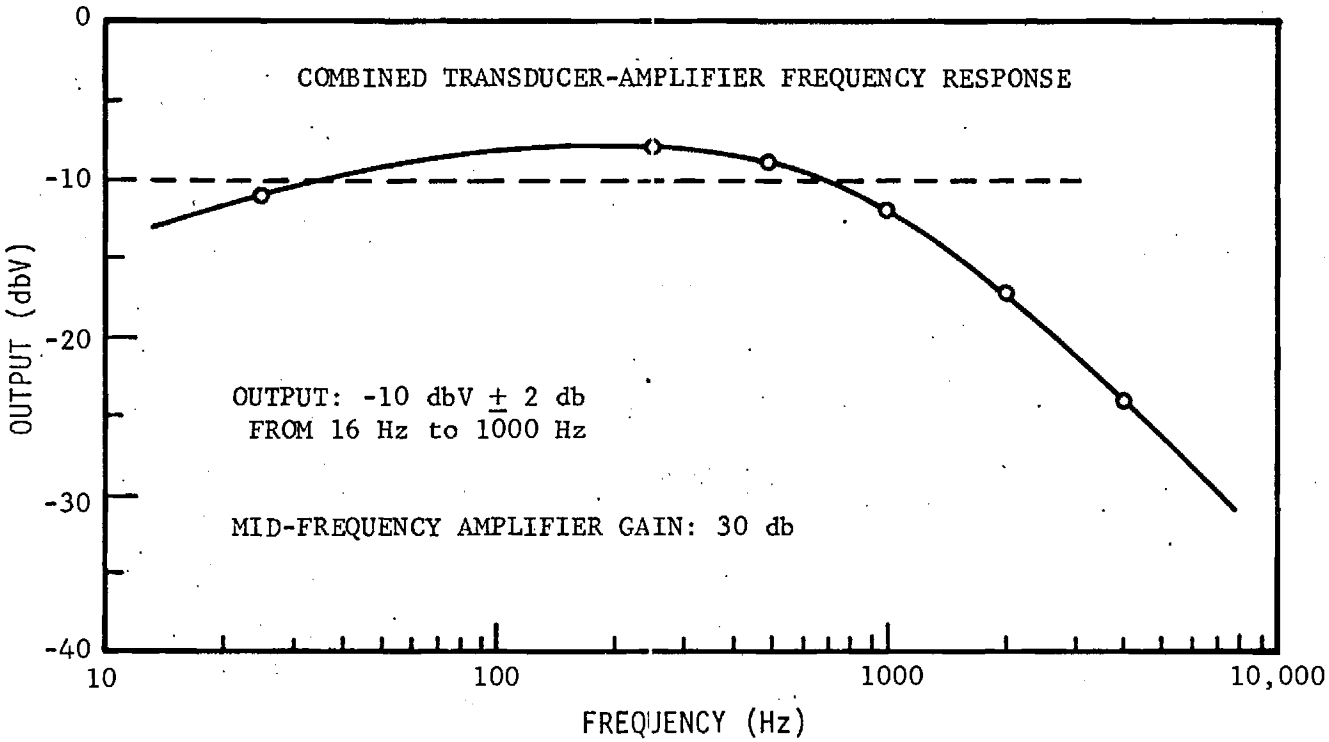

COMBINED TRANSDUCER-AMPLIFIER FREQUENCY RESPONSE
OUTPUT: -10 dbV ± 2 db
FROM 16 Hz to 1000 Hz
MID-FREQUENCY AMPLIFIER GAIN: 30 db
OUTPUT (dbV)
0
-10
-20
-30
-40
10
100
1000
10,000
FREQUENCY (Hz)

Figure 3

3. Collaborative Experiments at Emory University.

Nine visits to Emory University have been made by Georgia Tech personnel in connection with this project to test the equipment and obtain some preliminary results using the esophageal transducer system. The effects of various drugs on the amplitude of the heart sounds of anesthetized dogs have been clearly observed. Changes in the heart rate were also easily distinguishable as a result of drug administration.

C. Summary and Follow-up.

As a result of the present Contract an esophageal phonocardiography transducer system has been built at Georgia Tech and validated in experiments conducted at Emory University. The silver electrode which was mounted over the sensing element in the third model of the transducer provided a method for reproducible placement of the transducer in the esophagus for obtaining optimum sound recordings.

On the basis of the work done under this Contract and a follow-up project which resulted in a development of another transducer, which included temperature measurement capability in addition to sound and ECG, an abstract of a paper has been submitted to the Association for the Advancement of Medical Instrumentation for presentation at the 7th Annual Meeting in Las Vegas, Nevada, April 24-26, 1972. The full Abstract is given as Appendix II in this report.

A paper is being prepared for submission to the Review of Scientific Instruments which will describe the esophageal transducer system including experimental data on the effect of drugs on the heart sound characteristics.

Respectfully submitted,

M. E. Sikorski
Principal Investigator

MES/ml

Appendix I

Transistor Transducer Isolated Control Circuit

Georgia Institute of Technology Project A-1258

October 6, 1970

Frank R. Williamson

Introduction

The control circuit is an isolated-input audio amplifier with bias circuitry for operating a cardiomicrophone (consisting of a transistor transducer) as the input source. Electrical isolation of the transducer circuit is accomplished by modulating the transducer output upon a 250 kilohertz carrier and transformer-coupling it to a demodulator/amplifier output circuit. Reference is made to the attached circuit diagram and board layout for a circuit detail description. Power for the two separate circuits is provided by batteries in order to maintain maximum isolation and to insure a minimum signal corruption from power line frequencies. Internal filtering limits the bandpass of the amplifier to between 25 hertz and 4 kilohertz. The upper and lower frequency cutoffs are accomplished by single-section RC circuits. This filter is not intended to interfere with frequencies of interest, and serves primarily to reduce the very large low frequency components below 25 hertz that would tend to overdrive electronics connected to the signal output. In most applications, additional filtering may be desirable to emphasize frequency components of particular interest. The output impedance of the unit is in the range of one kilohm or less for the passband discussed above. Total voltage gain of the system from transducer to output was measured to be approximately 80 with the output gain potentiometer in the maximum (clockwise) position. In this maximum gain condition a peak dynamic range of approximately 1.2 volts should be expected at the output before visible distortion occurs.

Operating Instructions

On-Off Switch - Electrical power to both circuits is controlled by the On-Off toggle switch. This switch must be in the ON condition for both normal operation of the circuit and for the battery checks. In the interest of conserving battery power, certain compromises in circuit design have been made that may occassionally cause the internal oscillator to fail to start. This is associated with a lack of output signal and may be corrected by turning the unit off and then on again.

Meter Function Switch - This switch is located directly below the panel meter and controls its operation and scale factors. Before and after each period of use, the batteries should be checked by placing the meter-function switch in the BATT. 1 and BATT. 2 positions. The meter scale factor in these positions is 12.5 volts full scale, which corresponds to a numerical division by two of the numbers on the meter dial. Battery 1 is nominally 9 volts and battery 2 is nominally 8.4 volts. It is anticipated that a battery voltage drop of 10 percent below these values will allow satisfactory operation of the unit. This 10 percent voltage drop on either battery corresponds to a gain loss in the associated circuit of approximately 5 percent. It is important to check the battery <u>after</u> a period of use since the voltage reading then will be a truer indication of the battery condition. (The starting value after a period of rest may be higher due to depolarization and will be somewhat misleading.)

The BIAS position connects the meter to the transistor transducer to read the collector-to-emitter voltage. This is the normal position of the switch during operation, so that this voltage may be monitored for drifts due to change in the operating temperature of the transducer. The meter range is 2.5 volts full scale in this condition, which corresponds to a division by 10 of the numbers on the meter scale.

The two remaining switch positions of COARSE ZERO and FINE ZERO are used in connection with an internal circuit adjustment (Offset Control R_{11}) to adjust the modulator-demodulator circuit for its maximum dynamic range. This is not a frequent procedure and should be checked periodically (about every 4 to 8 weeks) to check for aging of circuit components. If significant drift from zero occurs, adjust R_{11} until the meter reads zero using the COARSE and then the FINE settings as needed.

<u>Bias Control</u> - This potentiometer sets the operating point of the transistor transducer to a value of collector-to-emitter voltage that is recommended for the specific transducer being used. (This value will usually be 2.0 volts.) Temperature changes of the transistor sensor normally affect the operating point and require a readjustment of the Bias Control to insure identical operating conditions.

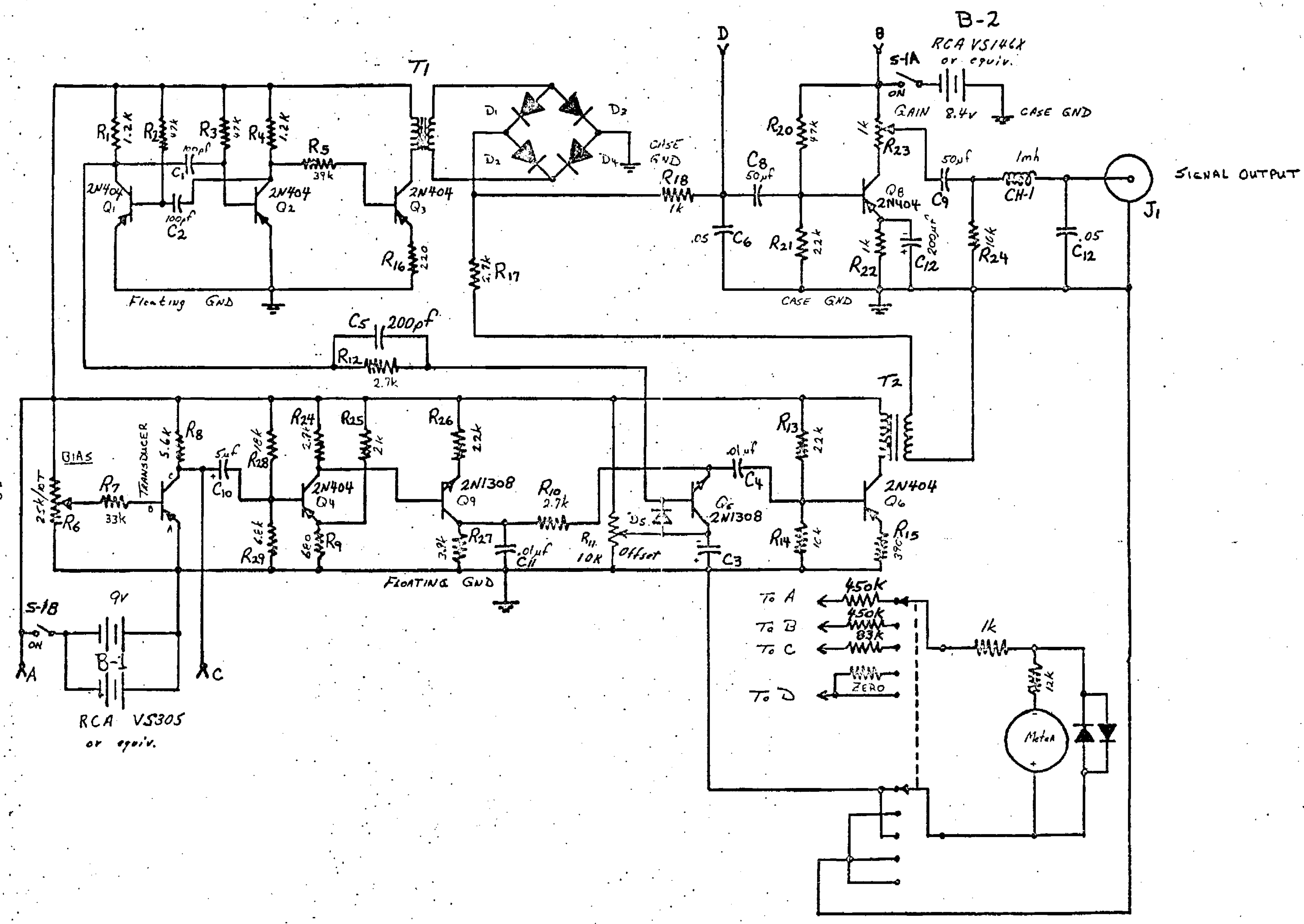
<u>Gain Control</u> - An attenuator is included on the front panel to provide a gain reduction capability in the output signal. In order to insure the maximum signal-to-noise ratio in the output, the control is normally left in the maximum or clockwise position unless signal attenuation is needed.

<u>Grounding Post</u> - A terminal post is provided at one end of the unit to allow the output circuit ground and chassis to be connected to a quality ground when desired.

<u>Input Connector</u> - The catheter is coupled to the control circuitry through a 4-pin connector located on one end of the unit.

<u>Output Connector</u> - The output connector is a standard phone jack that provides a single-ended output signal referenced to the common output-circuit and chassis ground.

<u>Battery Changes</u> - Battery changes are accomplished by removing the bottom cover of the unit. It is recommended that battery replacement be attempted only when the On-Off switch is in the OFF position. The output electronics is powered by an 8.4 volt mercury cell (RCA type VS 146X or equivalent) that is located in a holding clip at the end of the unit. The old battery is removed from the clip and the new one pressed in and attached to the battery connector. The floating electronics is powered by two 9 volt batteries (RCA type VS 305 or equivalent) connected in parallel. These batteries are changed by sliding them from the open end of the plastic battery box and inserting and connecting the new cells.



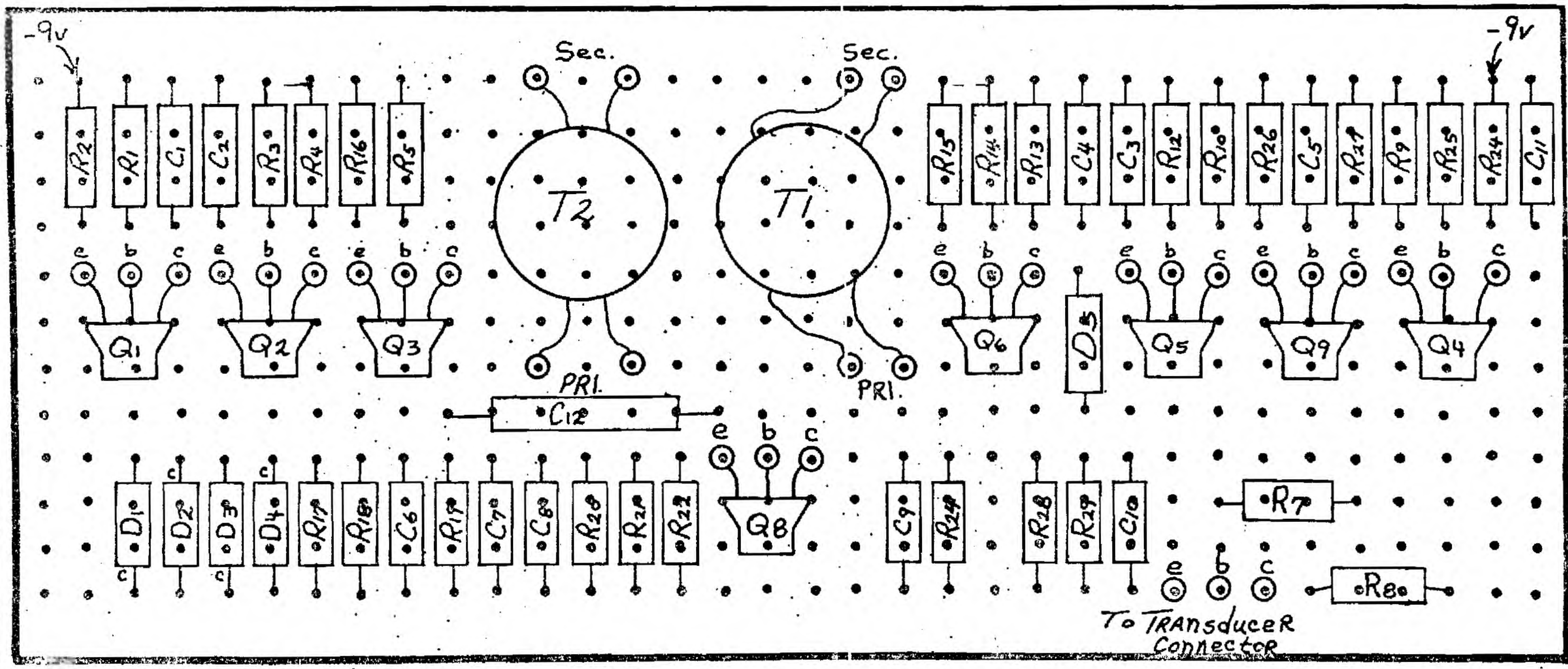
-10-

SEPT 21, 1970
Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
PHYSICAL SCIENCES DIVISION — SPECIAL PROBLEMS BRANCH

UNIT PLANNING SHEET for ALDEN TERMINAL CARD MOUNTING SYSTEM
CARD #650ATMS-1B

SCHEMATIC

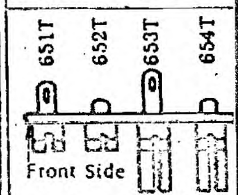
LAYOUT- *MAIN BOARD*



TERMINAL LEGEND

Head Mounted on Front Side
○651T ⊘653T
⊗652T ●654T

Head Mounted on Back Side
651T 653T
652T 654T



Head Mounted on Front Side
Top View

Ratcheted Slots oriented vertically as shown unless otherwise specified.

Front View

9/57

3 5/8" x 8 1/2" x 1/16"

COMPANY	crkt.	dr. by SAP	date 10/1/70
	proj. A-1258	chkd. RW	app. FD

Appendix II

MULTIFUNCTION ESOPHAGEAL TRANSDUCER FOR ANESTHESIA RESEARCH *

by

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Atlanta, Georgia 30332

and

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* Abstract of a paper submitted for presentation at the 7th Annual Meeting of the Association for the Advancement of Medical Instrumentation in Las Vegas, Nevada, April 24-26, 1972.

ABSTRACT

A multifunction electro-mechanical transducer system has been developed for anesthesia research. It consists of a heart sound sensor, an ECG electrode, and a thermistor mounted close to the tip of a 9F catheter, suitable for insertion into the esophagus. The microphone is placed at the tip and on the inside of the catheter tube. A cylindrical ECG silver electrode coaxially mounted over the sound probe is used to standardize the position of the microphone. This is accomplished by placing the tip of the catheter 2.5 cm above the point at which the esophageal unipolar electro-cardiograph lead detects a biphasic "P" wave. The thermistor bead is placed in the proximity of the electrode to allow monitoring of body temperature during the surgical procedure.

A special electrical shock-proof control circuit has been developed for the heart sound transducer. The control circuit is an isolated-input audio amplifier with bias circuitry for operating the transistor sound transducer as the input source. Electrical isolation is accomplished by modulating the transducer output and transformer-coupling it to a demodulator/amplifier output circuit. Internal filtering limits the bandpass of the amplifier to between 25 Hz and 4 kHz. The experimental results obtained in a number of studies on dogs show large changes in the amplitude of the first and second heart sounds as a result of administration of anesthetic drugs. A thorough computer analysis of the data is expected to yield quantitative correlations with the dose of the agents. Recently, recording of heart sound has begun on anesthetized patients undergoing surgery.

This work has been supported by NIH Grants HE 12616 and HE 11317.