THERMISTORS AS BLOOD FLOW-RATE TRANSDUCERS

by

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ABSTRACT

The need for a flow-sensitive instrument for fundamental medical research is briefly discussed and heated thermistors are shown to be suitable due to their sensitivity to flow cooling. Their small size also allows mounting on catheter tips. However they are shown to have a detrimental response to fluid temperature changes. A method of compensating for temperature effects is developed and the characteristics of a device using this compensation are shown.

ACKNOWLEDGEMENTS

I would like to express my appreciation to Professor William D. Jackson for bringing this problem to my attention, and for the technical suggestions he offered during the pursuit of the final results.

I would also like to express my thanks to Dr. Richard Gorlin and his associates, Dr. Hood, Dr. Krasnow, and Dr. Rolett of the Peter Bent Brigham Hospital EKG Laboratory for graciously allowing me use of their equipment, and for their technical assistance during the course of the experiments.

I am also indebted to Mr. Fred Roseberry and Mr. George Leach of the R.L.E. Tube Laboratory without whose technical assistance and welding ability this thesis could not have been a success.

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INTRODUCTION

Flow Measurement for Medical Research

There is a great need for a flow sensitive instrument for fundamental medical research. The requirements placed on such an instrument are 1) the sensor should be sufficiently small so as to allow mounting on a catheter tip, which could then be placed directly into a blood vessel; 2) the instrument should provide an output voltage proportional to the flow rate such that, by using an appropriate recorder, flow rate as a function of time could be obtained; and 3) it should be possible for non-technical personnel to operate the instrument.

An instrument capable of meeting the above requirements would yield fundamental information about the heart. Simultaneous electrocardiogram temperature and flow measurements, combined with chemical tests of the blood could produce a complete picture of energy input to the heart, mechanical work performed, and heat lost to surroundings. This vital information would increase our limited understanding of the complex action of the heart.

Flow Measurement Using Thermistors

Thermistors meet the above requirements for flow sensitive ~~sensitive~~ tranducers. They are small, temperature sensitive resistive devices made from a semiconductor-like ceramic material, and can be made sensitive to flow by heating them directly or indirectly to a temperature slightly above that of the surrounding fluid. Flow past the thermistor cools it in proportion to the flow rate, and an output voltage proportional to flow may be obtained by monitoring the resistance of the thermistor. Pruslin, in a previous thesis (1), has described the fundamental thermistor action and the method of direct heating.

The resistance of the thermistor may be represented as:

$$R=R'\exp[1/T - 1/T']B$$

where R' = resistance at 273 degrees K = T'

and B = 4000 $\pm$ 115 degrees K.

Changes of resistance over small temperature ranges are linear:

$$dR/R = -AdT$$

where A = -4 per cent per degree C at 25 degrees C.

Pruslin found this temperature dependence so large an effect that even small temperature changes of the order of .05 degrees C completely obscured the effects due to flow. Mellander and Rushmer (2), using an indirectly heated thermistor to measure flow and a second thermistor to compensate for temperature change of the fluid, obtained a linear relationship between output voltage and flow, for a range of flow rates between 100 and 1000 cc/min.

It was the purpose of this project to develop a flowmeter using a directly heated thermistor as the sensing element and a second thermistor to compensate for fluid temperature changes.

CHARACTERISTICS OF A THERMISTOR UNDER CHANGING FLOW AND TEMPERATURE CONDITIONS

Equipment Preparation

With the need for temperature compensation of a thermistor flow transducer in mind, a dual thermistor probe was constructed as in Fig. 1. Due to the extreme fragility of the probe it was necessary to provide special mounting in the flow channel to prevent breakage of the thermistor leads. The flow channel is illustrated in Fig. 2. The flow rate was calibrated using a stopwatch and a large graduate cylinder to yield a curve of flow rate versus hydraulic head as shown in Fig. 3.

To obtain flow rate and temperature information, one thermistor was heated above the fluid temperature by passing a comparatively large current through it (2ma.). This current was obtained from a regulated current source (3). The large D.C. component was balanced out using a battery and a helipot, and the unbalance due to temperature or flow changes was displayed directly on a 25mv/cm Sanborn Recorder. The other ther-

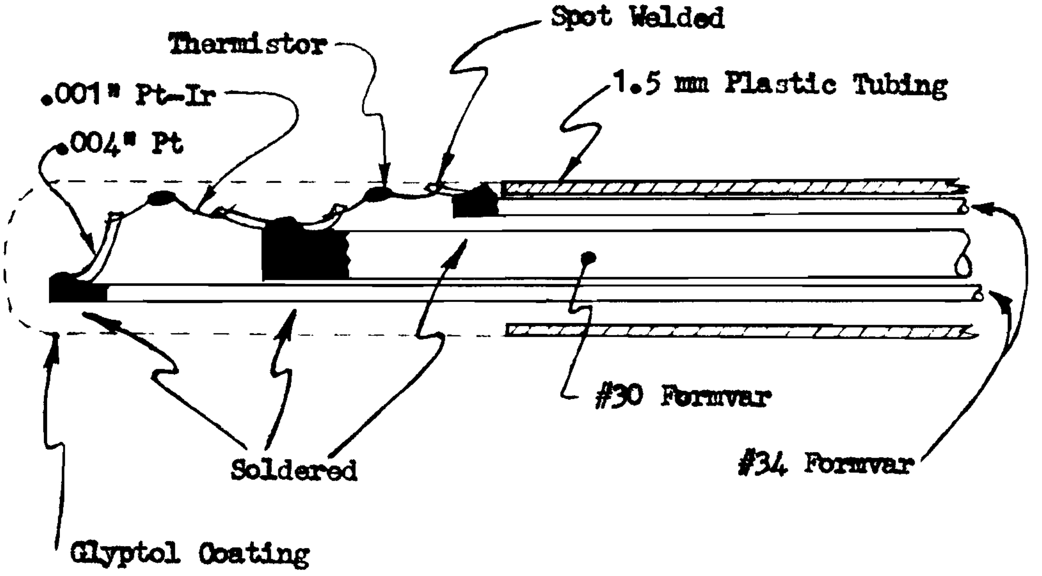
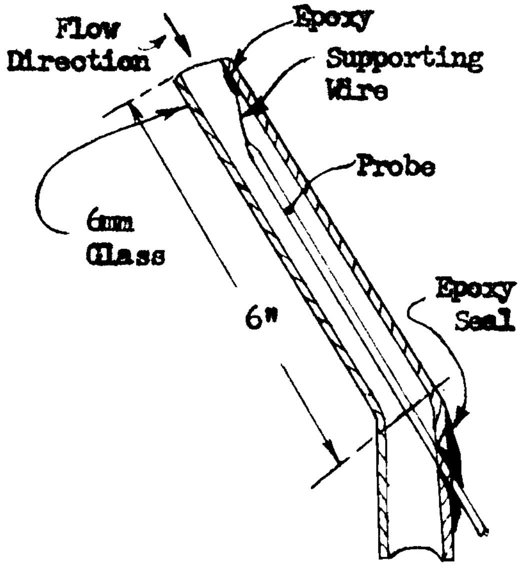
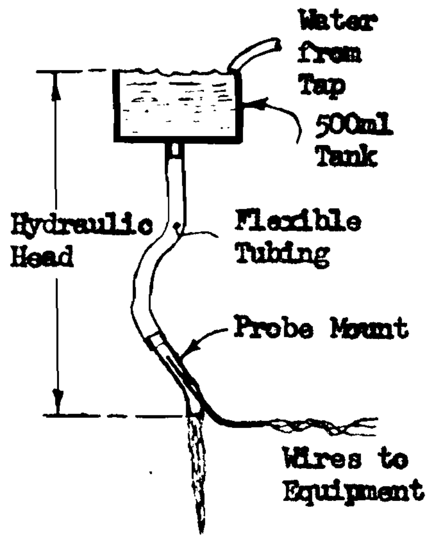


Figure 1. Details of Probe Construction



Probe Mounting



Flow Channel Arrangement

Figure 2.

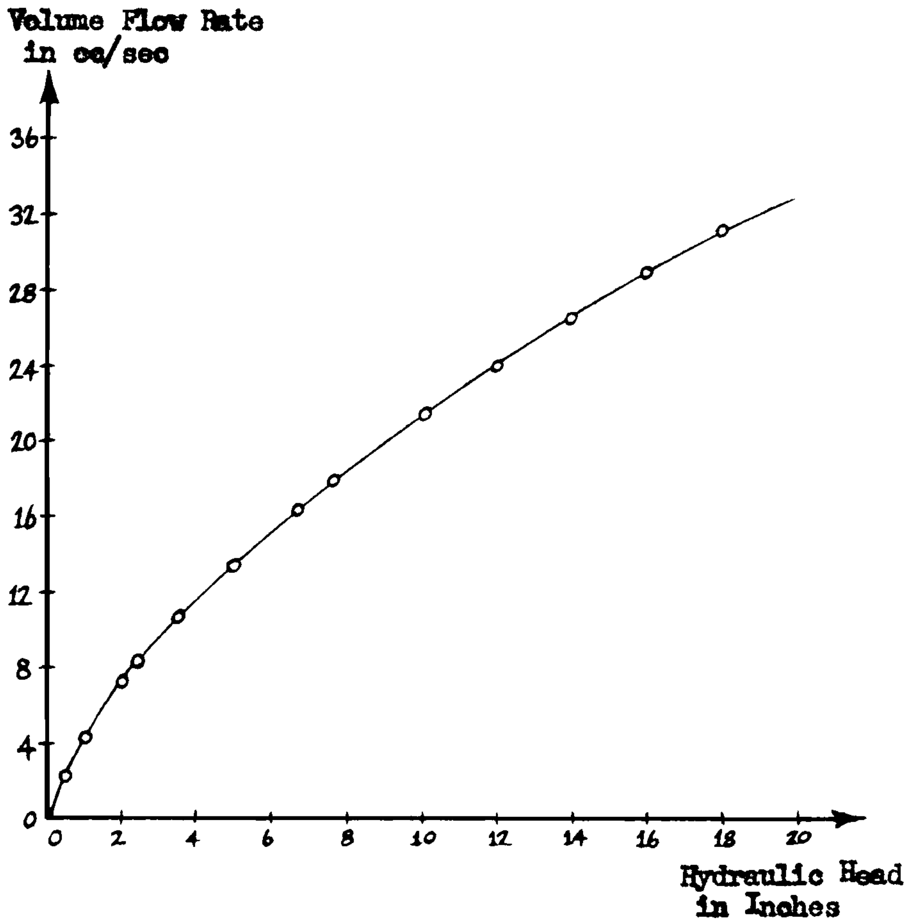


Figure 3. Calibration of Flow Circuit

mistor was used to monitor the fluid temperature. Since it was desired that this thermistor be insensitive to flow cooling, only a very small current (50uA RMS) was used for measuring purposes. Due to this small current it was necessary to design a very high gain, quasi-chopperized amplifier to yield useful voltages for temperature measurement. A sensitivity of .025 degrees C/cm was obtained when used with a Sanborn Recorder. (For circuit diagrams of the aforementioned instruments see APPENDIX A).

Experimental Procedure

Due to the medical implications of this flowmeter, water at approximately 37 degrees C was used as the fluid because of its similarity to blood. To gather data, the hydraulic head of the flow circuit was adjusted to the height desired to yield a constant flow rate. The fluid temperature was then adjusted above 37.4 degrees C (36.6 to 37.4 degrees C was taken as the normal range of blood temperature.) Introduction of a bolus of cold water into the flow circuit caused a gradual reduction in temperature as it diffused through the system, and after a time the temperature returned to normal. This process was repeated for other flow rates yielding Sanborn recordings of output voltage versus temperature at constant flow rates. This data was plotted into the family of curves shown in Fig. 4.

It can be seen from Fig. 4 that above a certain cutoff volume flow rate the effects due to flow rate and temperature changes are linear, suggesting that temperature compensation should not be difficult to obtain.

Above the cutoff, cooling of the thermistor is primarily due to convection; below the cutoff to conduction. Voltages obtained below the knee of the curve were erratic and non-reproducible. However this is not a major problem as the most interesting flow rates to medical researchers usually are in excess of 1cc/sec. (Arterial velocities can be as high as 200cm/sec with flow rates of several hundred cc/sec.

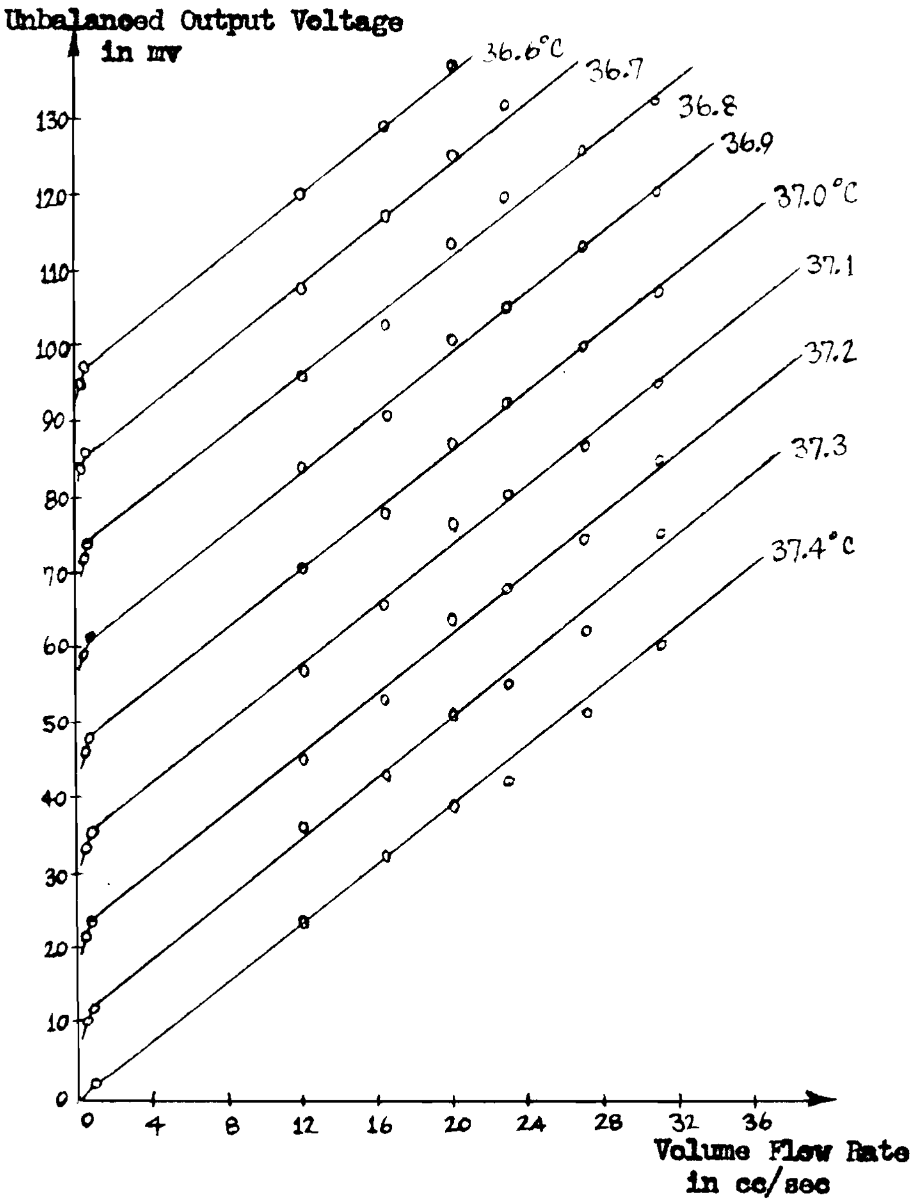


Figure 4. Thermistor Temperature and Flow Characteristics

TEMPERATURE COMPENSATED FLOWMETER

It can be seen from Fig. 4 that if the temperature characteristics of the two thermistors in the probe can be matched over the small temperature range of interest an output proportional only to flow rate can be attained.

Different initial resistances of the heated and unheated thermistor produce a matching problem. Also the characteristic A depends on temperature and is different for the two thermistors. Production tolerance in B = 4000 $\pm$ 115 degrees K also introduces dissimilarities (4). However it can be shown that by the introduction of a potentiometer (resistance the same order of magnitude as the thermistor) in series with each thermistor and another potentiometer (resistance large compared to thermistor) in parallel with the series combination, the thermistors can be made to track over a small temperature range. At the highest temperature of interest the low resistance potentiometer is adjusted and at the lowest temperature the high resistance potentiometer is adjusted. Repeated adjustment at low and high temperatures finally produces tracking. The process is similar to aligning the RF and oscillator stages of a superheterodyne.

The above process was instrumented (See APPENDIX B) and the output voltage versus flow rate is shown in Fig. 5. The rise time of the instrument ranged from 0.1 to 1.5 sec. depending on the flow rate, with the best response at high flow rates.

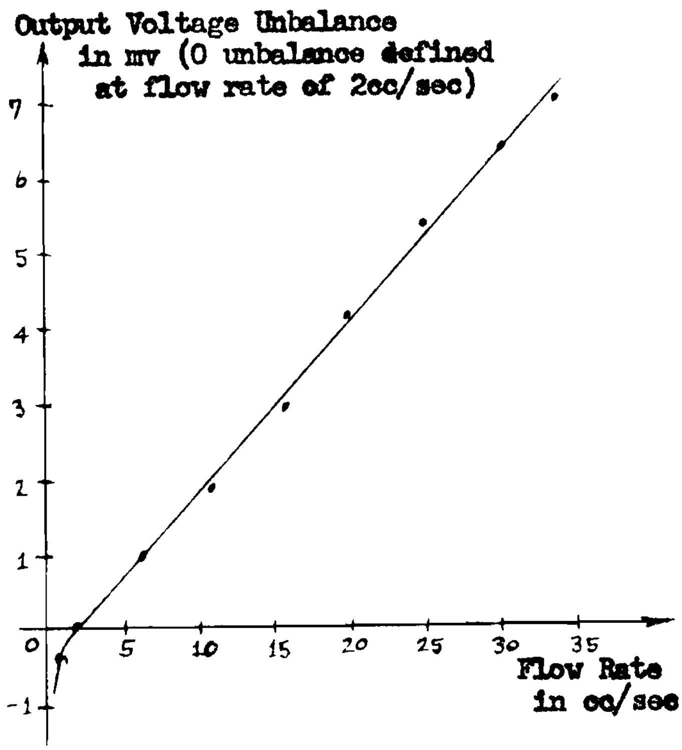


Figure 5. Output Characteristics of Compensated Device

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

A temperature compensated, directly heated thermistor flowmeter has been shown to be feasible. The transducer is small and mountable on a catheter tip allowing its use in blood vessels. Although the trimming potentiometers are difficult to adjust, once they are set the device is simple to operate. Ageing of thermistor characteristics has been shown not to be a problem (4,5). Thus the instrument meets the requirements initially set forth. Additionally the compensating thermistor may be used for simultaneous temperature measurement. On the debit side transient response was too slow to allow accurate reproduction of transients, but is sufficient for phase information.

The equipment used did not allow volume flow rates in excess of 31cc/sec. Time did not allow construction of new equipment to investigate higher flow rates in anticipation of turbulent flow as suggested by Pruslin. Future investigation in this area should show a noticeable change in cooling of the thermistor as the flow goes turbulent.

APPENDIX A

Circuit diagrams of the instrumentation used for temperature and flow measurements are shown in Fig. 6. When used with a VECO 32A7 thermistor the main amplifier is capable of producing an output of 1v/ degree C. This amplifier was initially designed for the Doctors at Peter Bent Brigham Hospital and has been used on humans, yielding instantaneous temperature measurements never before attained.

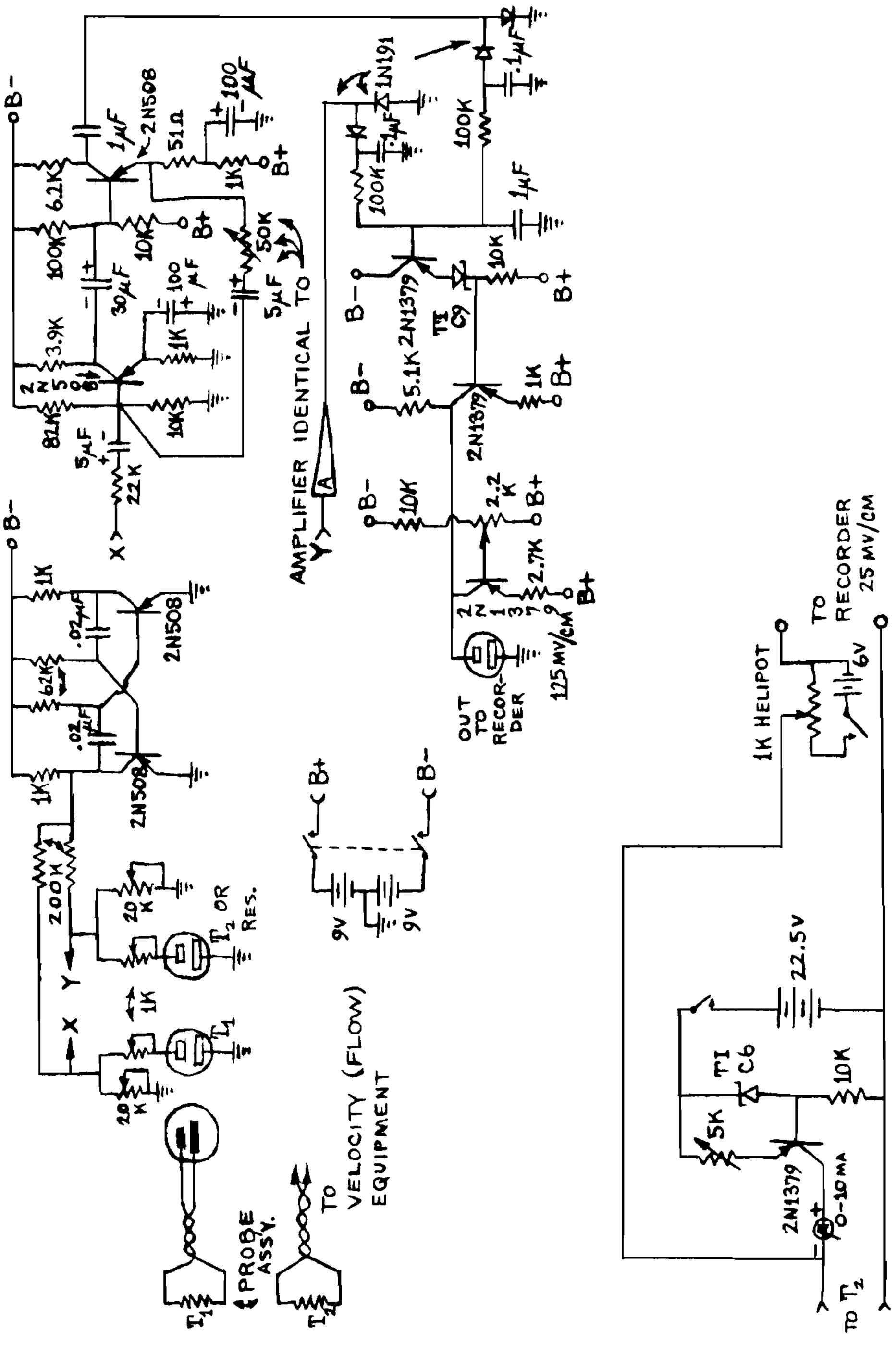


Figure 6. Instrumentation for Temperature & Flow Measurements

APPENDIX B

Circuit diagram of the temperature compensated flowmeter is shown in Fig. 7. The only unusual aspect of the circuit is the use of a transistor as the common emitter resistor in the differential amplifier.

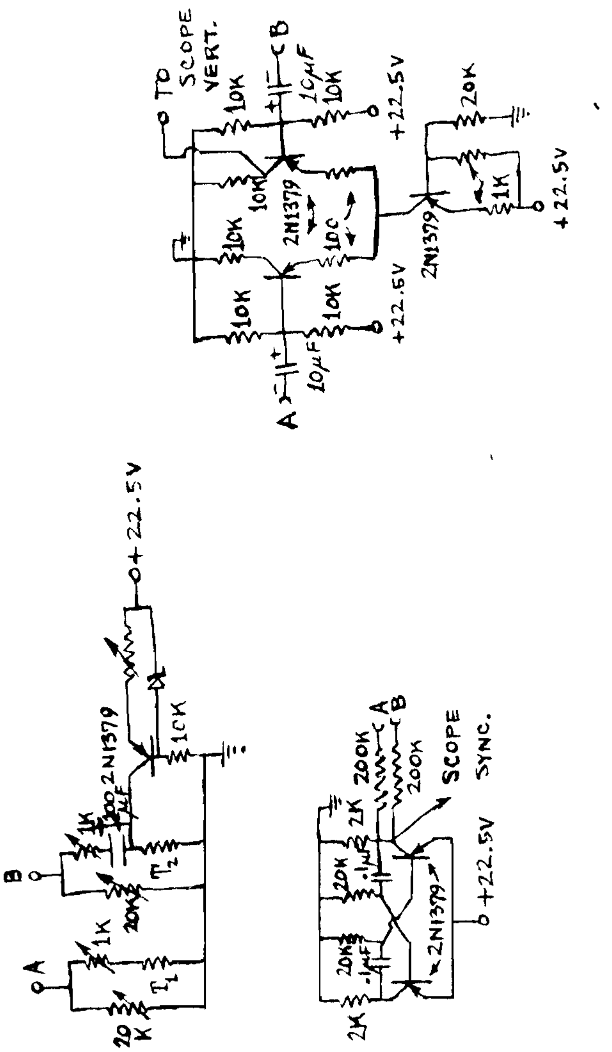


Figure 7. Final Device Circuity

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James Elbert Thompson — SB
(Name of Student) (Degree Applied for)

Your thesis as required for the degree specified above has been received by this department.

May 18 1962 — Elec. Eng.
(Date) (Department)

by M. McAuley
(Signature)

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Mr. James E. Thompson

Dear Sir:

I take pleasure in informing you that you have been recommended by the Faculty for the Degree of Bachelor of Science.

Very truly yours,

Philip Franklin

Secretary of the Faculty

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Director

December 24, 1962

James Thompson
6708 East Vernon Avenue
Scottsdale, Arizona

Dear Jim:

You'll be pleased to hear that your thermistor box has worked just beautifully for us, and we have diligently pursued thermal measurements. Other people are picking up on the problem within the MIT training grant program.

Best of regards.

Yours sincerely,

Richard Gorlin, M.D.

RGe