

MANEUVERABLE VACUUM CLEANER FOR THE HANDICAPPED

by

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A Thesis Submitted to the Faculty of the  
DEPARTMENT OF ELECTRICAL ENGINEERING  
In Partial Fulfillment of the Requirements  
For the Degree of  
MASTER OF SCIENCE  
In the Graduate College  
THE UNIVERSITY OF ARIZONA

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## ACKNOWLEDGMENTS

The author wishes to thank Dr. Theodore L. Williams for his guidance and encouragement in writing this thesis; also Dr. Reginald L. Call for his critical comments.

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## ABSTRACT

The purpose of this work is to present a novel concept in vacuum cleaner design. Through the use of a unique electrical circuit and physical design, control was maintained over a roving platform on which a vacuum cleaner was mounted.

Phase control is a method by which the speed of a motor may be made to vary. This method is normally used with alternating current motors but was developed and applied to a direct current motor. The motor in turn was used to drive a single wheel in both the forward and reverse directions while varying speed. Maneuverability over the roving platform was obtained through control of this single wheel. Left and right turning action was made available through the use of a second direct current motor.

The particular vacuum cleaner system described in this paper is directly applicable for use by the handicapped or other persons unable or unwilling to push a conventional cleaner.

## CHAPTER 1

### INTRODUCTION

The fictional robot has traditionally been a mobile device somewhat humanoid in appearance. However, while the humanoid robot has yet to make its appearance, robot devices are already with us.

Robot traffic signals replace the human policeman waving his arms. Chores are passed to robot washing machines and robot dishwashers. Telephones physically located miles apart are connected through switching networks handled completely by robots.

Professor Meredith Thring<sup>1</sup> of Queens Mary College has suggested that the minimal robot must include:

1. A method of self-propulsion and self-steering.
2. Power systems and control systems for propulsion and steering.
3. A computer memory for storing instructions and decision making.
4. Various senses (e.g., sight, hearing, the ability to sense position, and the ability to judge distance).

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<sup>1</sup>J. F. Young, Robotics (England: Redwood Press Limited, 1973), p. 4.

In terms of Thring's four characteristics, the roving vacuum cleaner described in the later sections of this paper did not constitute a robot. Although the propulsion and control systems were robotic qualities, decision making was left entirely to the discretion of the operator. This resulted in the distinct advantage of low cost and good control as the operator's senses and thinking process were incorporated into direct action by the roving platform.

A floor and carpet cleaning robot has been built by Mr. Benjamin Skora.<sup>2</sup> The adult-sized robot was 6 feet 8 inches tall and weighed 275 pounds. Power was derived from two 12 volt batteries normally found in an automobile. One battery was used to supply power to the electronics and the other to drive motors. Control of ambulation was achieved by telemetry and built in programs.

The Skora robot was too sophisticated for use by the layman and thus was impractical as a cleaning appliance for the American home. Other drawbacks included cost of construction and education of the operator in programming techniques.

The maneuverable vacuum cleaner described in this paper was designed to be low in cost and practical for use in the average home. The maneuverable vacuum system was

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<sup>2</sup>Linda Folkard-Stengel, "AROK," Interface, Vol. 2: (April, 1977), p. 38.

constructed on a circular frame. The frame stood on three casters set in a triangular pattern. A motorized wheel was placed in the center of the triangle. Sitting on the circular frame was a vacuum cleaner and turning motor. The turning motor positioned the circular frame in either a clockwise or counterclockwise direction. Control of the frame was provided by a control box which was attached to the vacuum system via an umbilical cord. A single potentiometer moved the platform in the forward or reverse directions while varying speed. A slide switch moved the platform toward the left or right.

## CHAPTER 2

### MECHANICAL ASSEMBLY

The fabrication of a maneuverable vacuum cleaner involved interfacing mechanical components with electrical circuitry. A unique physical design based on a triangular wheel structure provided stability and low construction cost. Following is a description of the various components which made up the physical design of the maneuverable vacuum cleaner. Figures are provided to identify the components and to illustrate mechanical linkages.

#### Roving Platform

The roving platform was constructed of sheet metal 3/32 inches thick. It stood 6.5 inches off the ground via three caster wheels arranged in a triangular pattern. The diameter of the circular platform was 13 inches. Figure 2.1 illustrates the physical design of the roving platform. As shown in Figure 2.1, a rubber center bumper and rubber bottom bumper were mounted in strategic locations to help prevent damage to furniture as the platform moved.

#### Motorized Wheel

The motorized wheel consisted of a 4.5 inch rubber tire wheel mounted in a swivel fork and gear driven by a

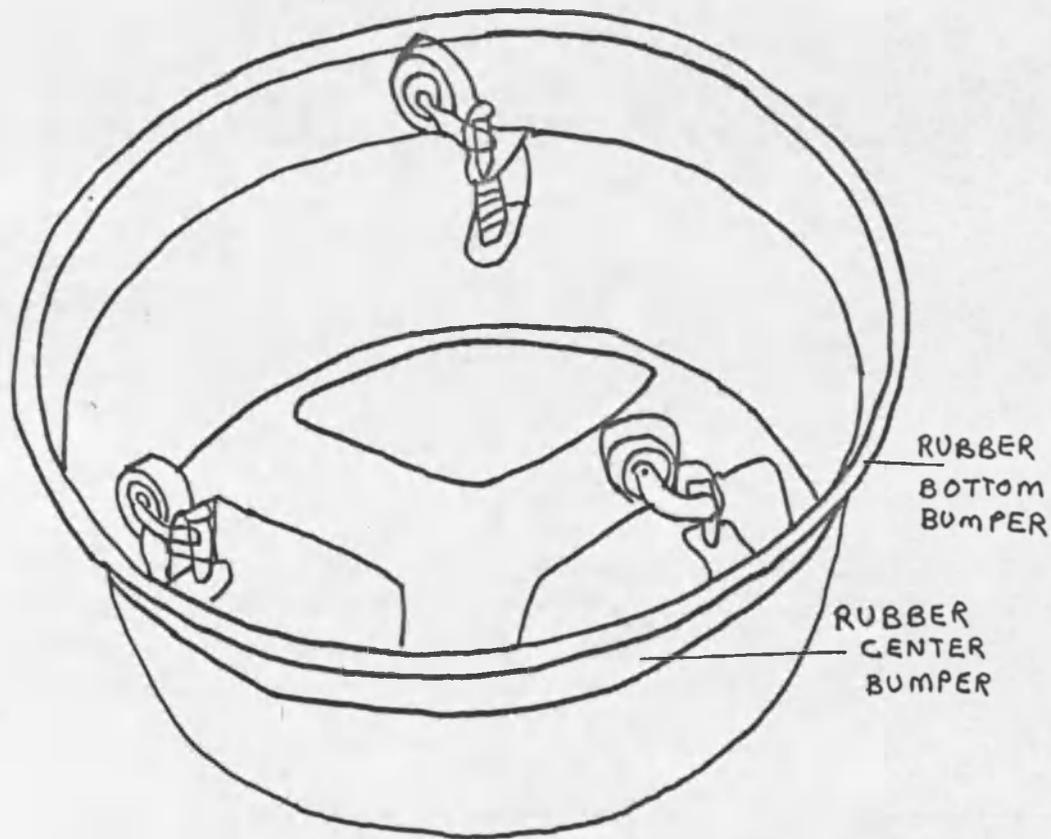


Figure 2.1. Bottom view showing the physical design of the roving platform.

permanent magnetic field, DC reversible motor. The motor operated on either a 6 volt or 12 volt battery. The no load current was 2 amperes and the "stall current" was 8 amperes. The operating current had a value between 2 and 8 amperes depending on the mechanical load of the motor, and the voltage used. The approximate "no load" speed was 120 RPM on 12 volts and 65 RPM on 6 volts. Figure 2.2 illustrates the motorized wheel.

#### Turning Motor

The motorized wheel was driven in either the clockwise or counterclockwise direction via chain drive by a permanent magnetic field, DC electric reversible motor. The motor operated on either 12 volts or 6 volts. The turning motor contained an internal gearhead and had a speed of 5 RPM at 6 volts and 10 RPM at 12 volts. Full load current was 50 milliamperes. Running torque was in excess of 40 ounce-inches at either voltage. The motor was two inches in diameter and 3-1/8 inches long excluding the shaft. The turning motor was also used to position one of the three casters left or right via a 1/5 inch pitch 15 inch long timing belt. The position of the caster was kept parallel with the motorized wheel and was used to steer the roving platform left or right.

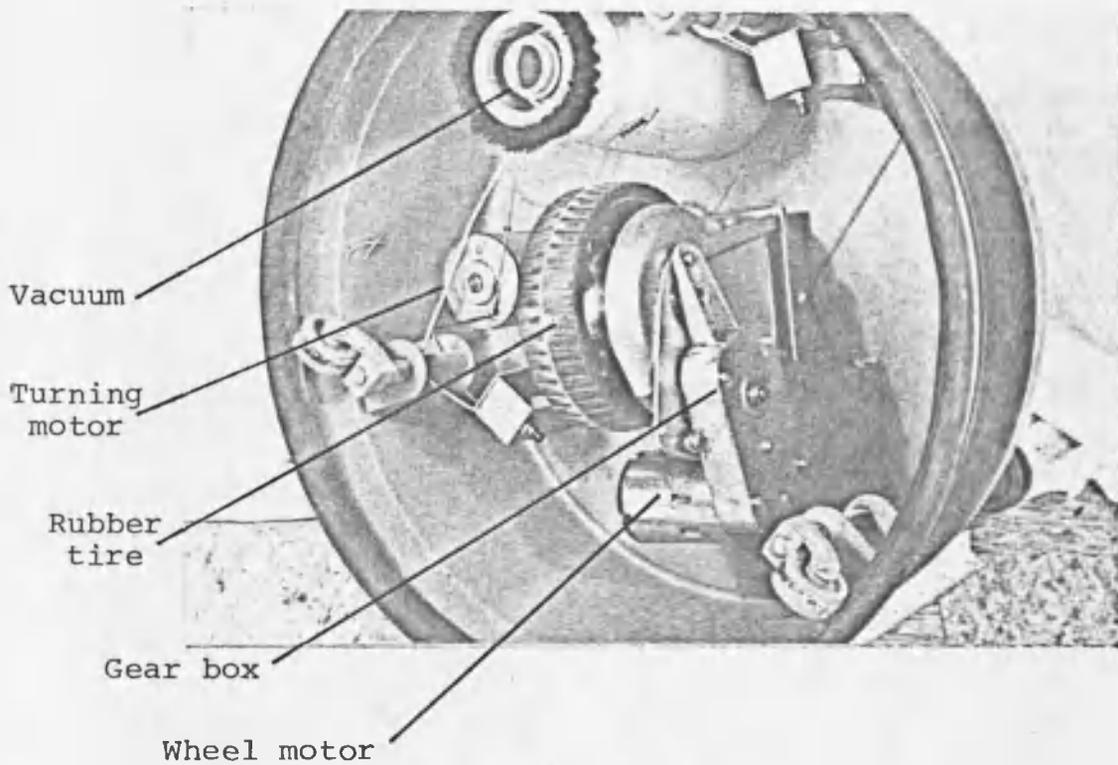


Figure 2.2. Illustration of the motorized wheel.

### Vacuum Cleaner

The vacuum cleaner incorporated into the roving platform was a modified 12 volt DC automobile vacuum cleaner. Modifications involved removing a jack from which the cleaner derived power. The jack was designed to be inserted into an automobile's cigarette lighter from which 12 volts could be obtained from the automobile's battery. The vacuum cleaner's dimensions were 11-1/2 inches long with a 4 inch on a side square base.

### Chain and Belt Drive

Two sprockets, one from the rear wheel and one from the chainwheel of a 24 inch bicycle had been incorporated into the roving platform. The rear wheel sprocket was mounted on the turning motor described on page 6. The chainwheel sprocket was used with a ball bearing bicycle mount and was located on the motorized wheel described on pages 4 and 6. The two sprockets in conjunction with a chain were used to transfer motion from the turning motor to the motorized wheel. Figure 2.3 illustrates the chain drive assembly.

A 1/5 inch pitch timing belt in conjunction with two timing gears was used to position one caster in parallel with the motorized wheel. The caster aided in steering the roving platform. Figure 2.4 illustrates the timing belt assembly.

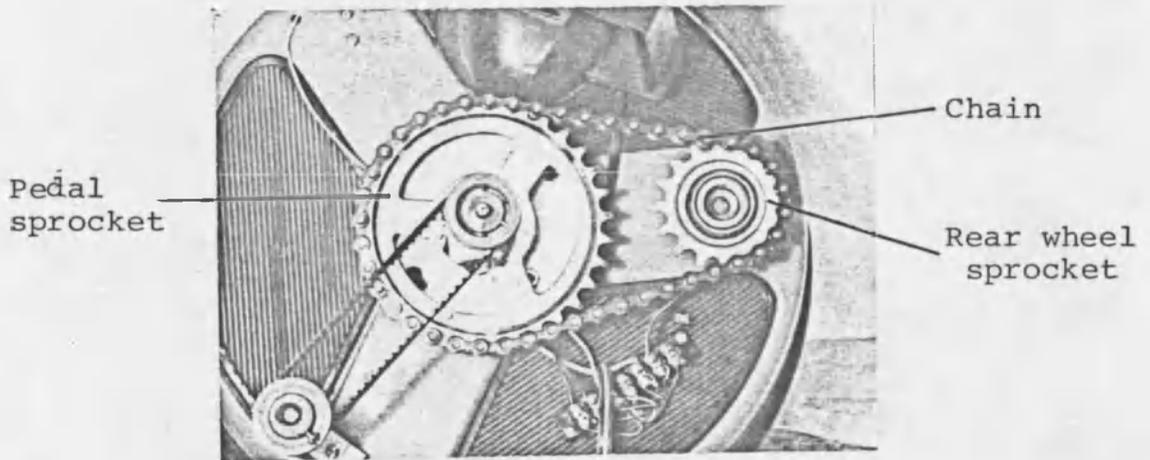


Figure 2.3. Top view showing chain drive.

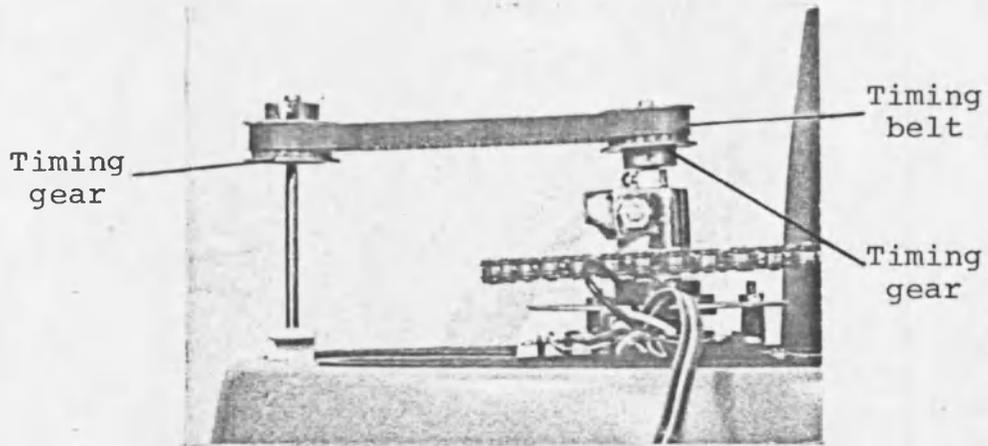


Figure 2.4. Illustration showing belt drive.

### Miscellaneous

Two normally closed push button limit switches were held by a sheet metal brace which was located on the underside of the platform. If the motorized wheel turned more than 90 degrees, the wheel pressed against a limit switch. The switch would open and voltage to the turning motor would be terminated. The wheel could however turn in the opposite direction before another limit switch would be engaged. Upon the successful interfacing of the various components described on the previous pages, the mechanical assembly of the maneuverable vacuum cleaner was completed. Remaining was the design and debugging of the electrical circuitry which would be used to control the platform. Figure 2.5 illustrates the overall construction of the roving vacuum cleaner. Figure 2.6 illustrates the same platform as viewed from the top.

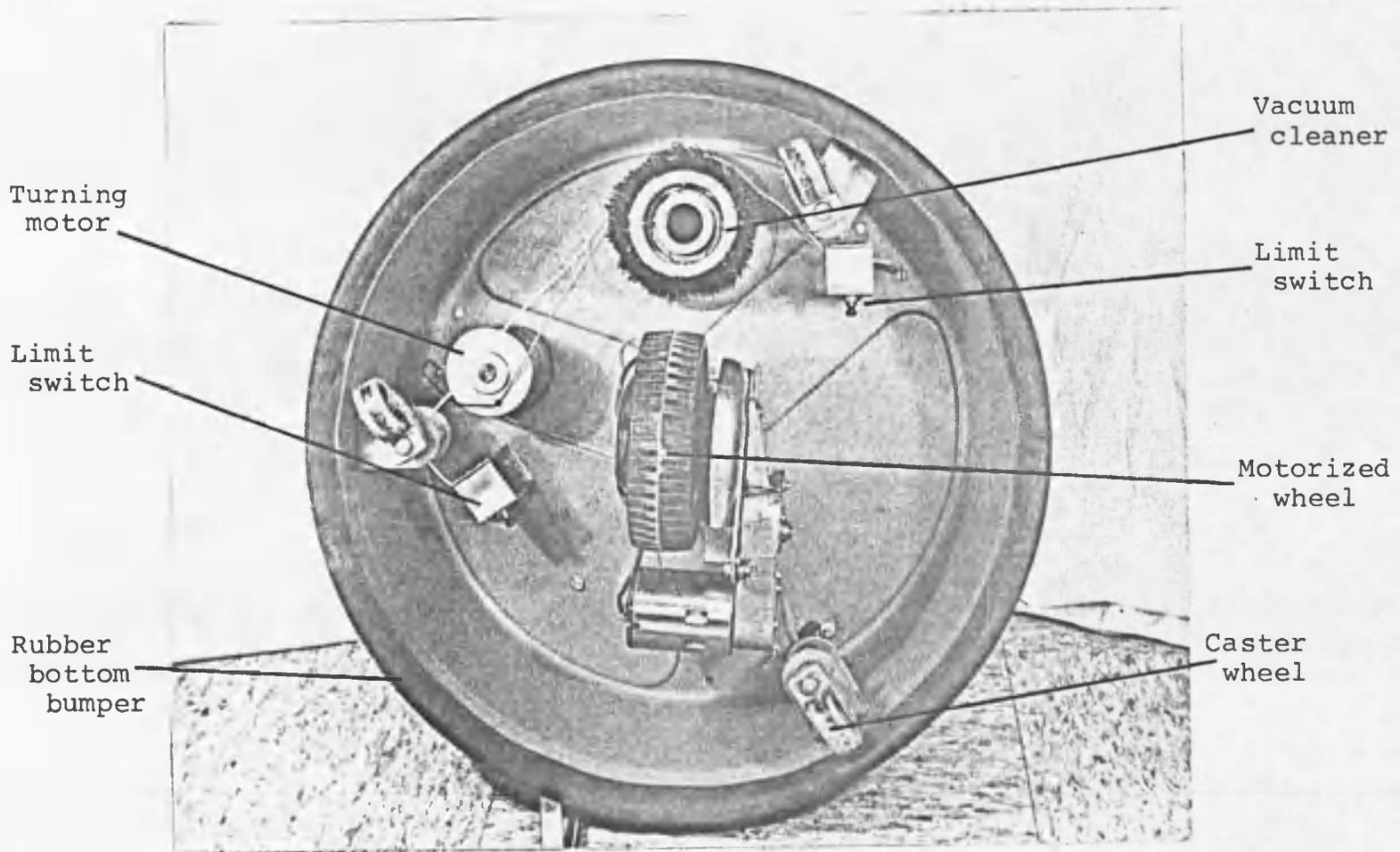


Figure 2.5. Illustration showing the mechanical assembly of the platform as viewed from the bottom.

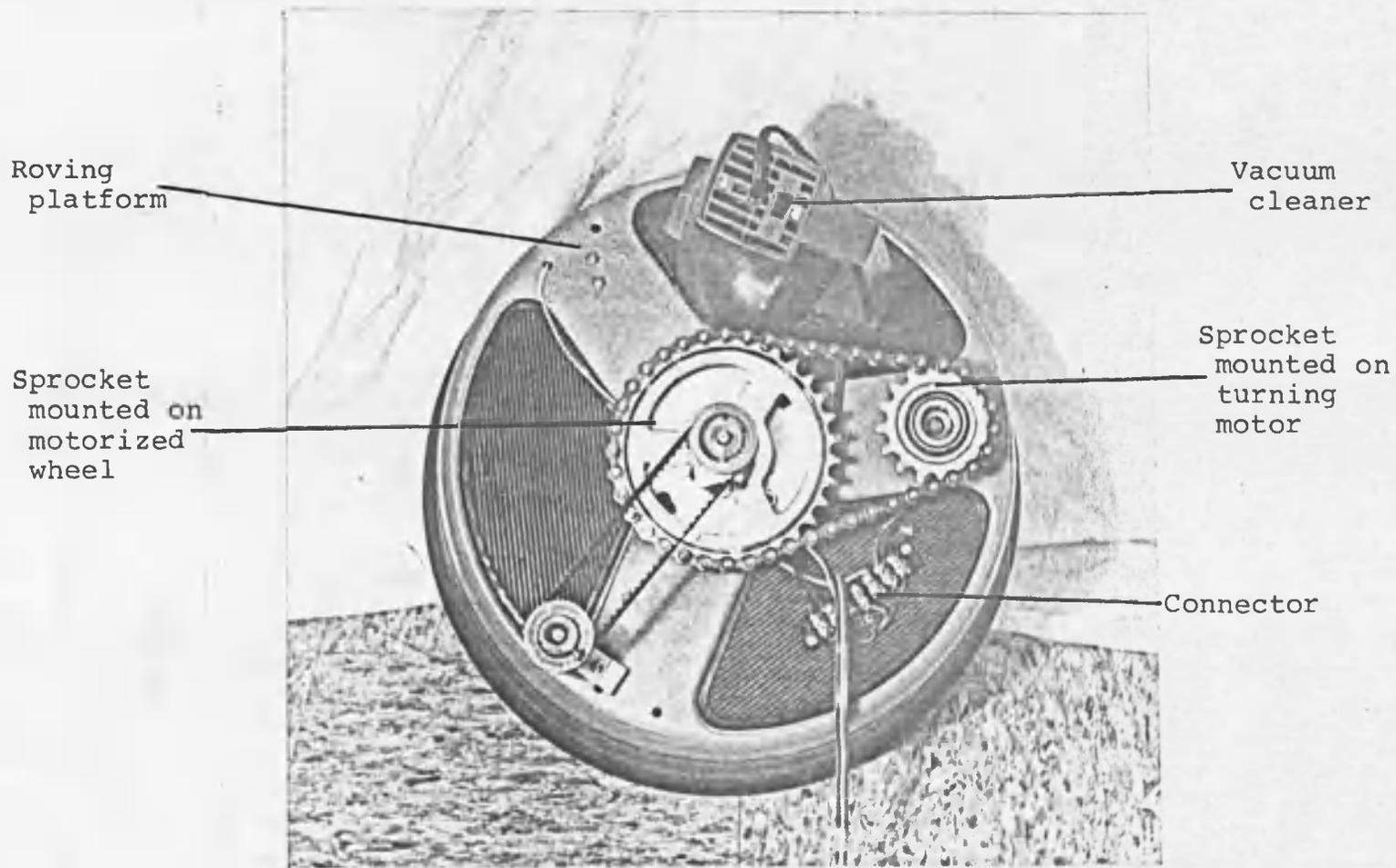


Figure 2.6. Illustration showing the mechanical assembly of the platform as viewed from the top.

## CHAPTER 3

### SOLID STATE DEVICES

The maneuverable vacuum cleaner utilized several solid state devices other than transistors to control movement of the roving platform. Since these devices may not be familiar to the reader, a short review follows.

#### Unijunction Transistors

Unlike the transistor which is a signal device, the UJT (unijunction transistor) is a breakdown device. Figure 3.1 shows the junction diagram, equivalent circuit, and electrical circuit for the UJT.

The homogenous N material shown in Figure 3.1a has a characteristic resistance of 4000 to 1000 ohms when measured between the bases. The resistance is denoted as  $R_{bb}$  in Figure 3.1b. When forward bias is applied to the emitter of the UJT with respect to  $B_1$ , holes are injected into the N material. This results in a sharp increase in conductivity from  $B_2$  to  $B_1$ .

There are several methods of fabricating UJT devices. Whether alloying or impurity diffusion is used, the UJT is stable against power supply changes. This is due to the fact that as the power supply voltage moves up

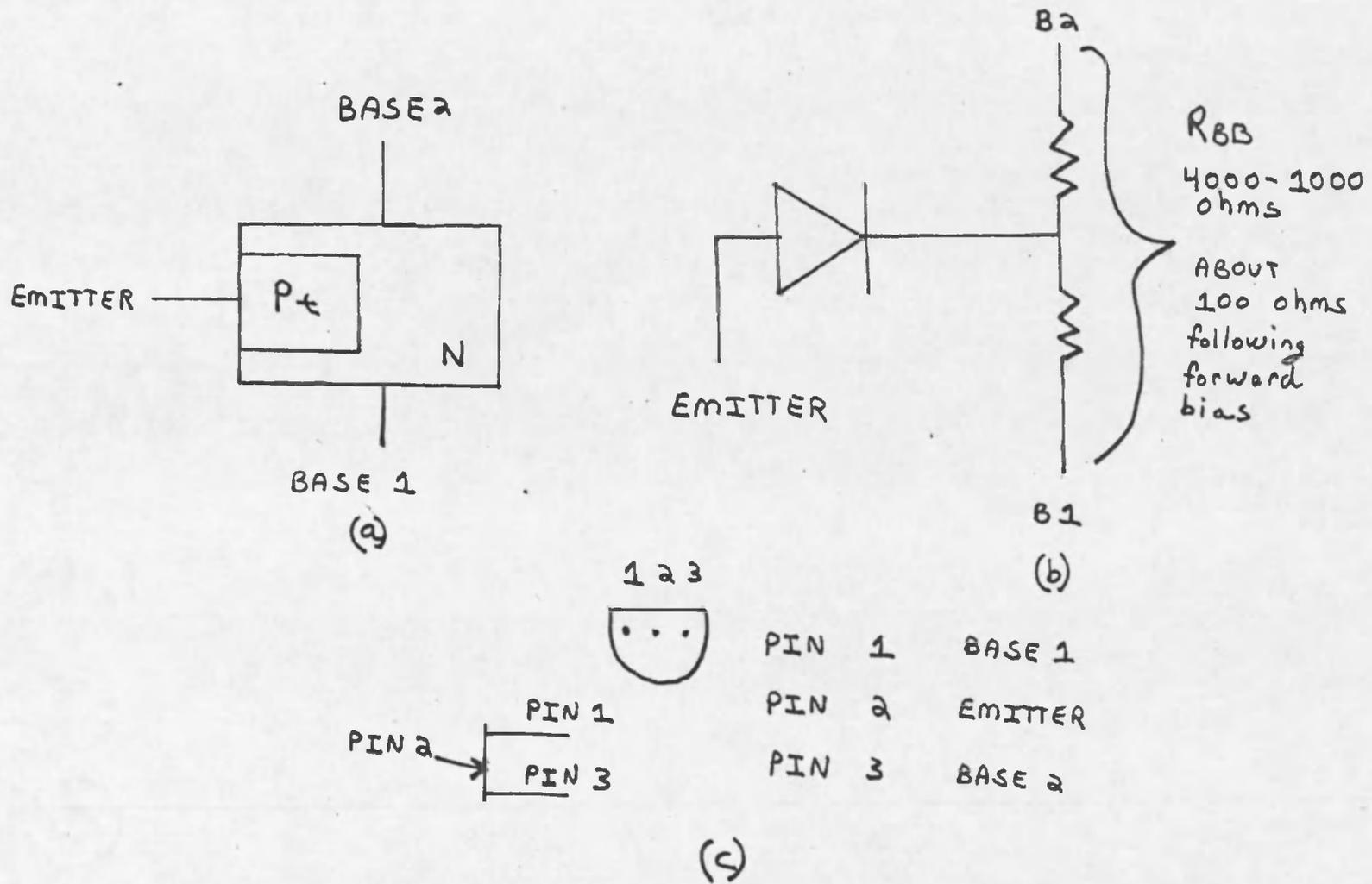


Figure 3.1. (a) Junction diagram, (b) equivalent circuit, (c) electrical symbol for the UJT.

or down, the critical voltage needed for breakdown of the device moves up or down accordingly. The UJT is often used to generate a source of pulses. The pulses are stable against power supply and temperature changes. The UJT specifications for the device incorporated within the roving platform control box may be found in the Motorola Solid State Semiconductor Data Library.

### Silicon Controlled Rectifiers

The SCR (silicon controlled rectifier) is a device that conducts in only one direction. But unlike a diode, the SCR may be "fired" by placing a certain amount of voltage on the gate. Once the SCR is turned "on," it can only be turned "off" when its power supply voltage becomes 0 volts or holding current for the device drops below a certain specified value.

The SCR is temperature sensitive. It is possible for thermal carriers to create false triggering.

The SCR is a four layered device as shown in Figure 3.2a. The transistor equivalent of the SCR is shown in Figure 3.2b. Figure 3.2c shows the electrical symbol for the SCR.

The SCR is used typically with an AC source. The SCR is placed in series with a load and is gated by a timing circuit. Normally the SCR is delayed in firing until some point in the half cycle is reached as shown in

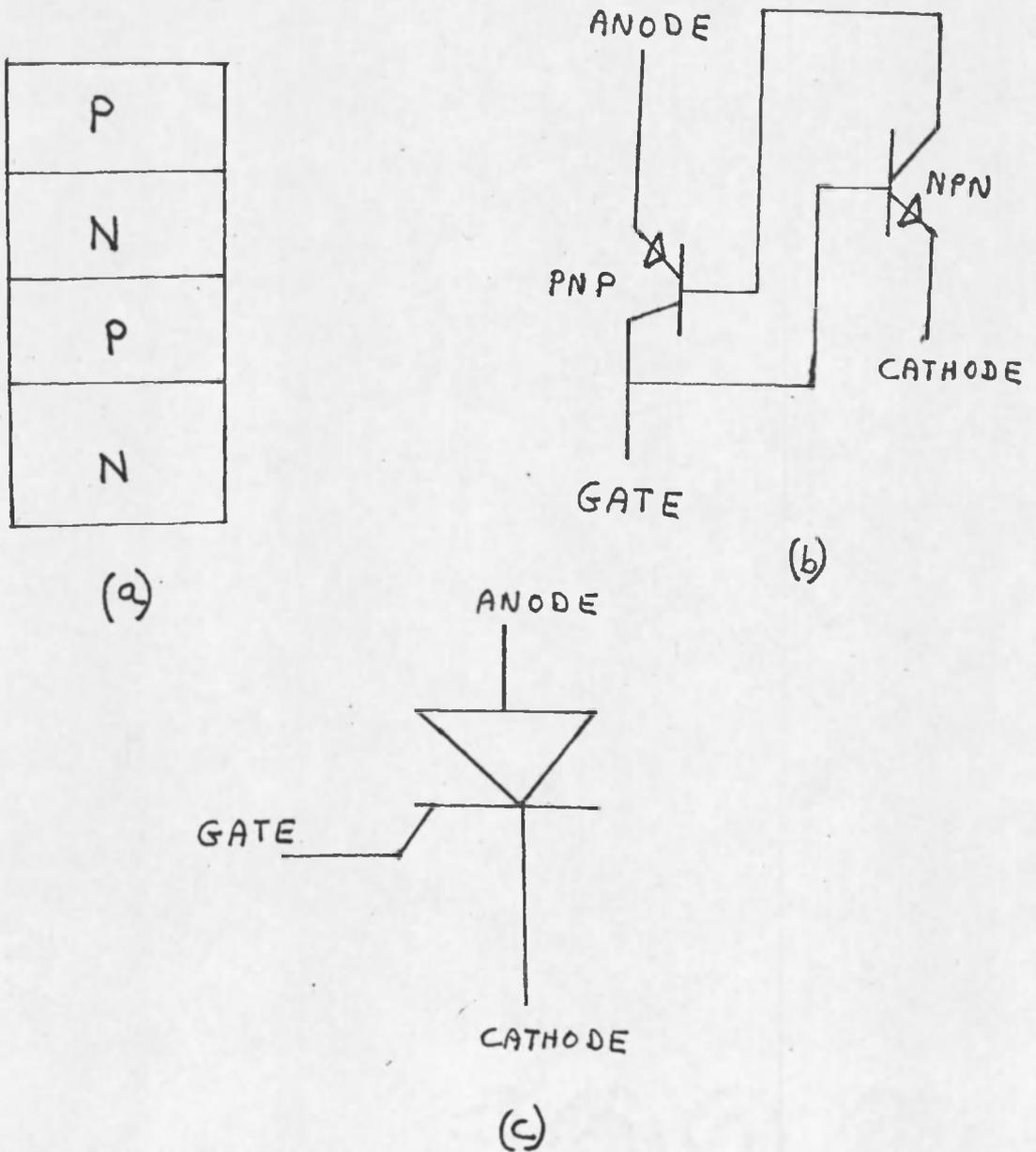


Figure 3.2. Characteristics of the SCR: (a) junction diagram, (b) transistor equivalent circuit, (c) electrical symbol.

Figure 3.3. Specifications for the SCR used within the roving platform control box may be found in the Motorola Solid State Semiconductor Data Library.

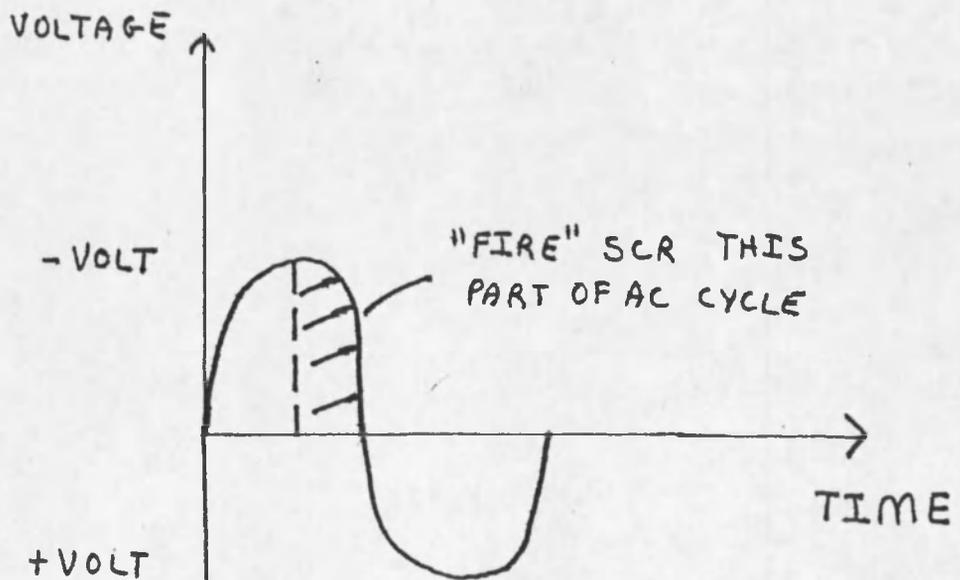
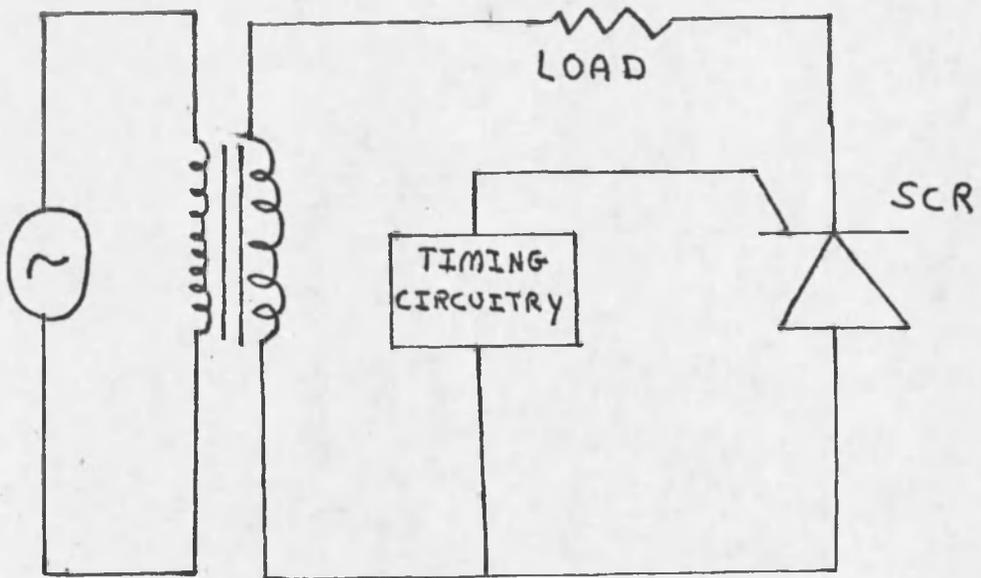


Figure 3.3. Typical application for the SCR.

## CHAPTER 4

### ELECTRONIC CIRCUITRY

The roving vacuum cleaner utilized a 12 volt and 25 volt direct current power supply to operate the vacuum cleaner and turning motor respectively. The two voltages were obtained through the full wave rectification and filtering of an alternating current produced from the output of step down transformers. Figure 4.1 shows the power supply circuit. In addition to these two voltages, a 25 volt alternating current produced from the output of a third step down transformer was used to help achieve phase control over the motorized wheel. All three power supply circuits were housed in a control box and connected to the roving cleaner through a seven conductor ribbon cable.

#### UJT Oscillator Circuit

Figure 4.2 illustrates an UJT oscillator circuit which makes up a large part of the electronics used to achieve phase control over the motorized wheel. A charging circuit was formed with a 0.1  $\mu\text{F}$ . capacitor and 100,000 ohm potentiometer. When battery voltage is first applied, the capacitor has 0 volts across its leads. The emitter of the UJT is reverse biased at the onset because the capacitor

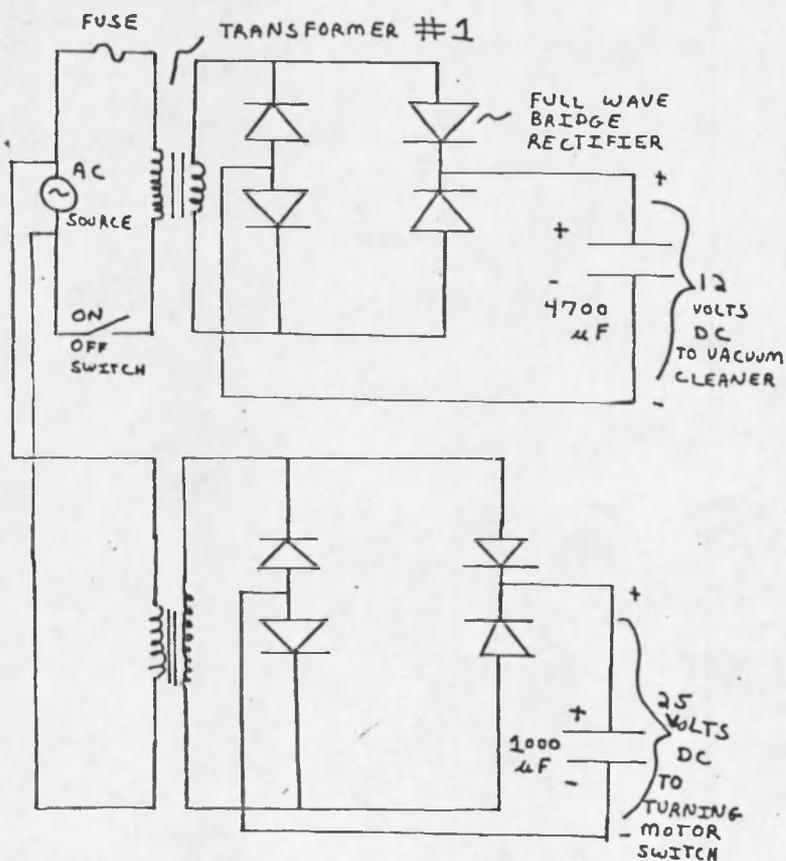


Figure 4.1. Power supply circuit for vacuum cleaner and turning motor.

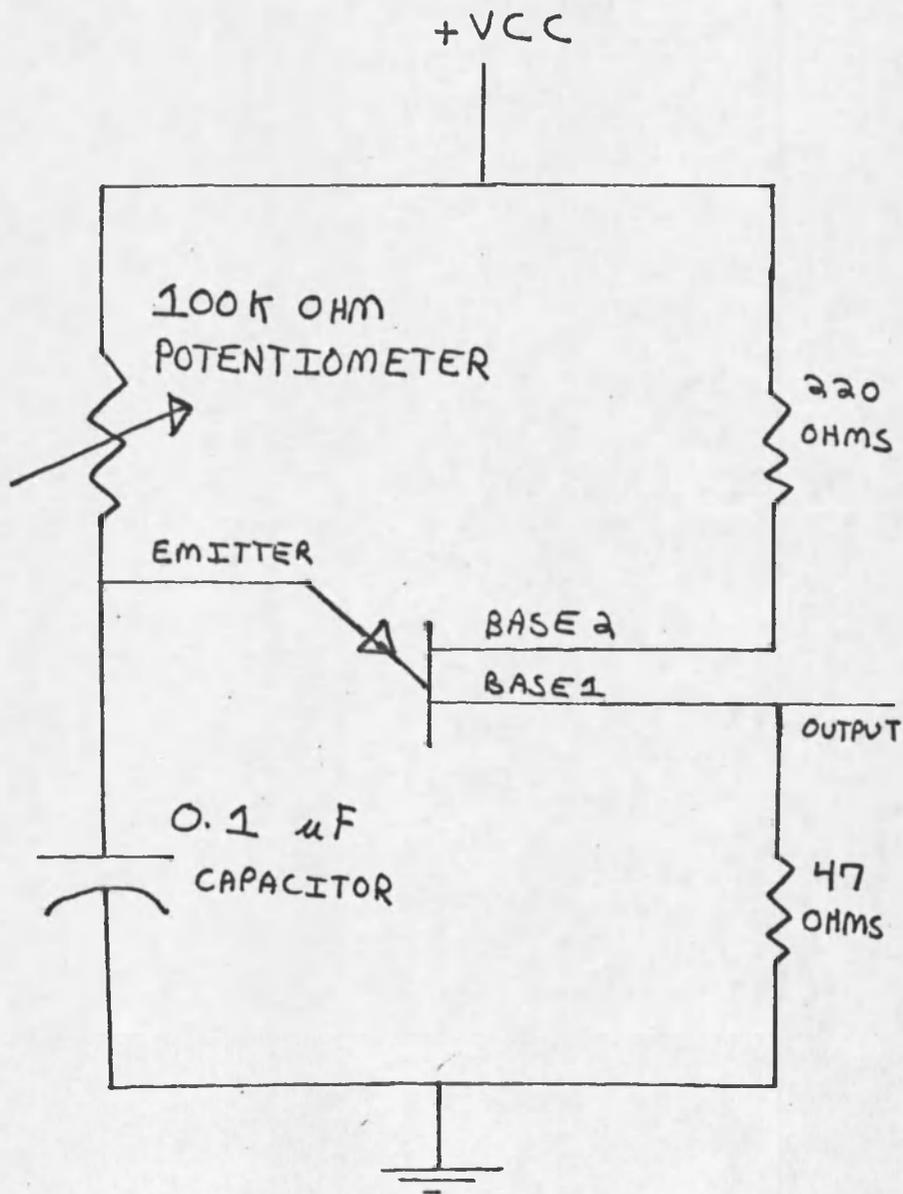


Figure 4.2, UJT oscillator circuit used to achieve phase control.

voltage is less than the voltage needed to "fire" the UJT. The capacitor dumps its charge through the UJT and 47 ohm resistor when the charging capacitor has a voltage drop that exceeds the standoff voltage of the UJT. This voltage drop across the capacitor keeps the UJT "off." Meanwhile, the capacitor begins to charge again. Each time the capacitor voltage exceeds the standoff voltage of the UJT, conduction occurs, placing an output pulse across the load. Figure 4.3 illustrates the voltage across the capacitor and output voltage as a function of time. Note that the minimum value of the capacitor voltage is called the valley voltage. At the valley voltage, the injection level of current from the emitter of the UJT has reduced the resistance of the bulk between the two bases of the UJT to about 100 ohms.

#### Phase Control of the Motorized Wheel

As shown in Figure 4.4, an identical set of timing circuits were used to "fire" one of two SCR's. Timing was provided by a 0.1  $\mu$ F. capacitor and variable dual potentiometer. The potentiometer consisted of the two sections labeled A and B. The potentiometer was wired so that as an A section of resistance increased, the B resistance section decreased by a corresponding amount. Suppose that the motorized wheel was "off." Neither SCR #1 nor #2 was "fired." The resistance of sections A and B of the

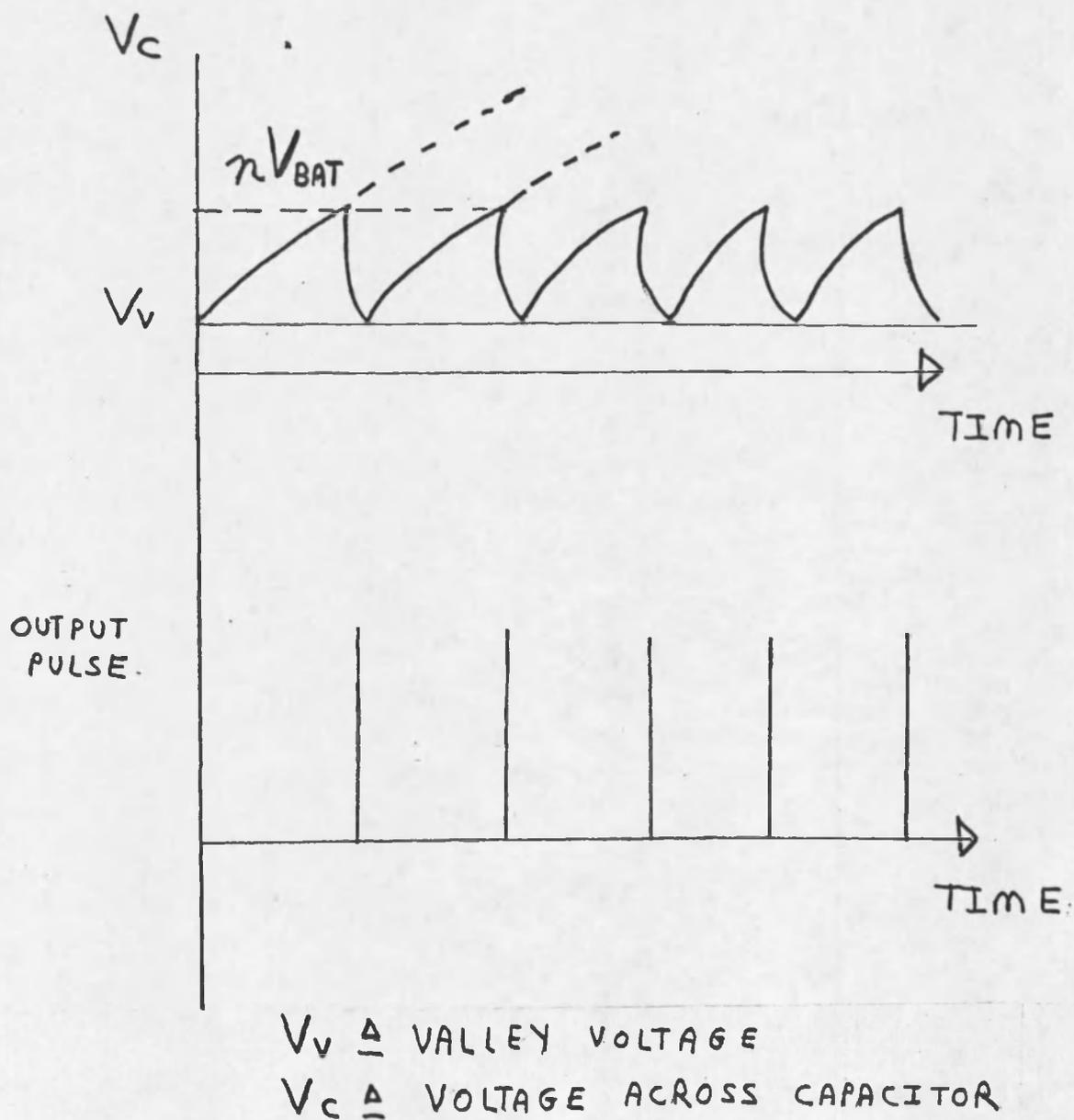


Figure 4.3. Voltage across the capacitor and output voltage as a function of time.

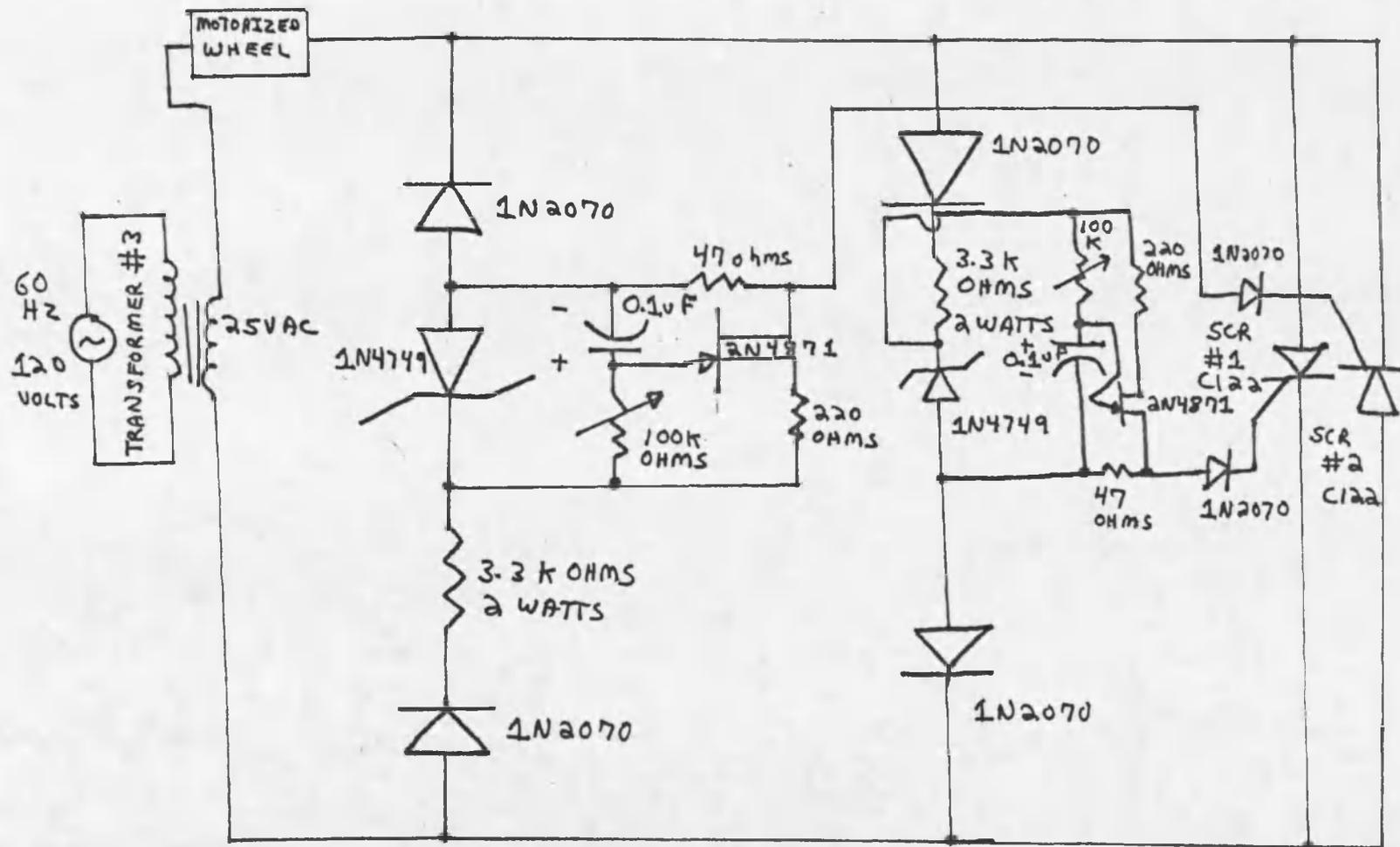


Figure 4.4. Complete phase control circuit controlling the motorized wheel.

potentiometer prevented either 0.1  $\mu$ F. capacitor from charging to a high enough voltage that would "fire" either UJT. Now suppose the control potentiometer is set to a new value of resistance. Let the resistance of section 1A decrease and the resistance of section 1B increase. The charging circuit involving the 0.1  $\mu$ F. capacitor and 1A section of resistance "fired" the UJT and SCR #1 turned "on." This resulted in the motorized wheel turning in the forward direction. The greater the amount of resistance of section 1B, the faster the motorized wheel turned in the forward direction. The fastest speed was obtained when the UJT was made to "fire" on the positive half cycles of the AC waveform. As the control potentiometer is turned in the opposite direction, the forward speed of the motorized wheel decreased as the resistance of the potentiometer section labeled 1A increased. When the resistance of section 1B was about equal to the resistance of section 1A, the motorized wheel turned "off." As the potentiometer was further turned, the resistance of section 1B became increasingly less than the resistance of section 1A. SCR #2 "fired," and the motorized wheel turned in the reverse direction. A further decrease in section 1B's resistance resulted in a faster reverse speed for the motorized wheel. Figures 4.5 and 4.6 illustrate phase control firing of SCR #1 and SCR #2 respectively.

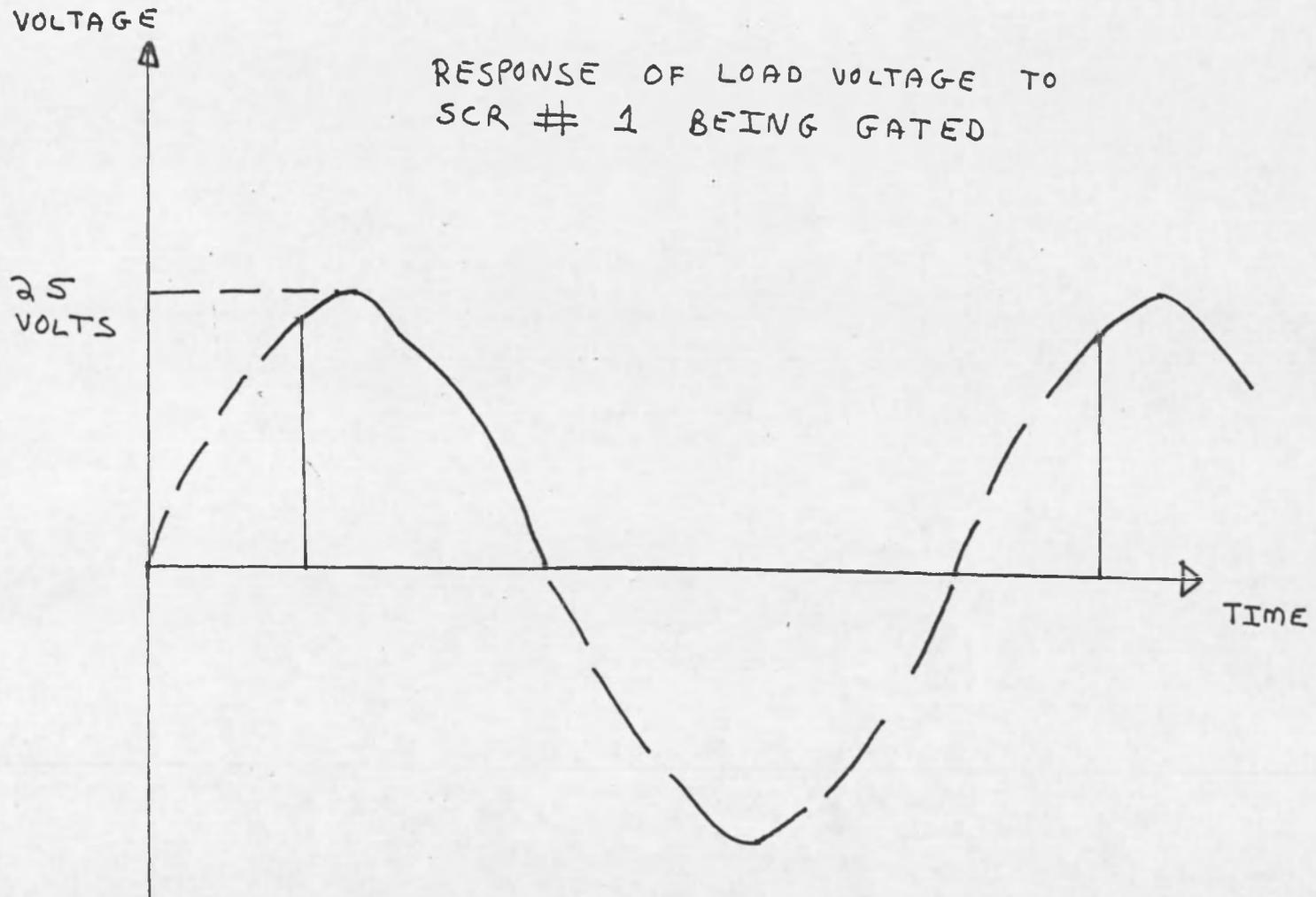


Figure 4.5. Phase control firing of SCR #1.

VOLTAGE

RESPONSE OF LOAD VOLTAGE TO  
SCR # 2 BEING GATED

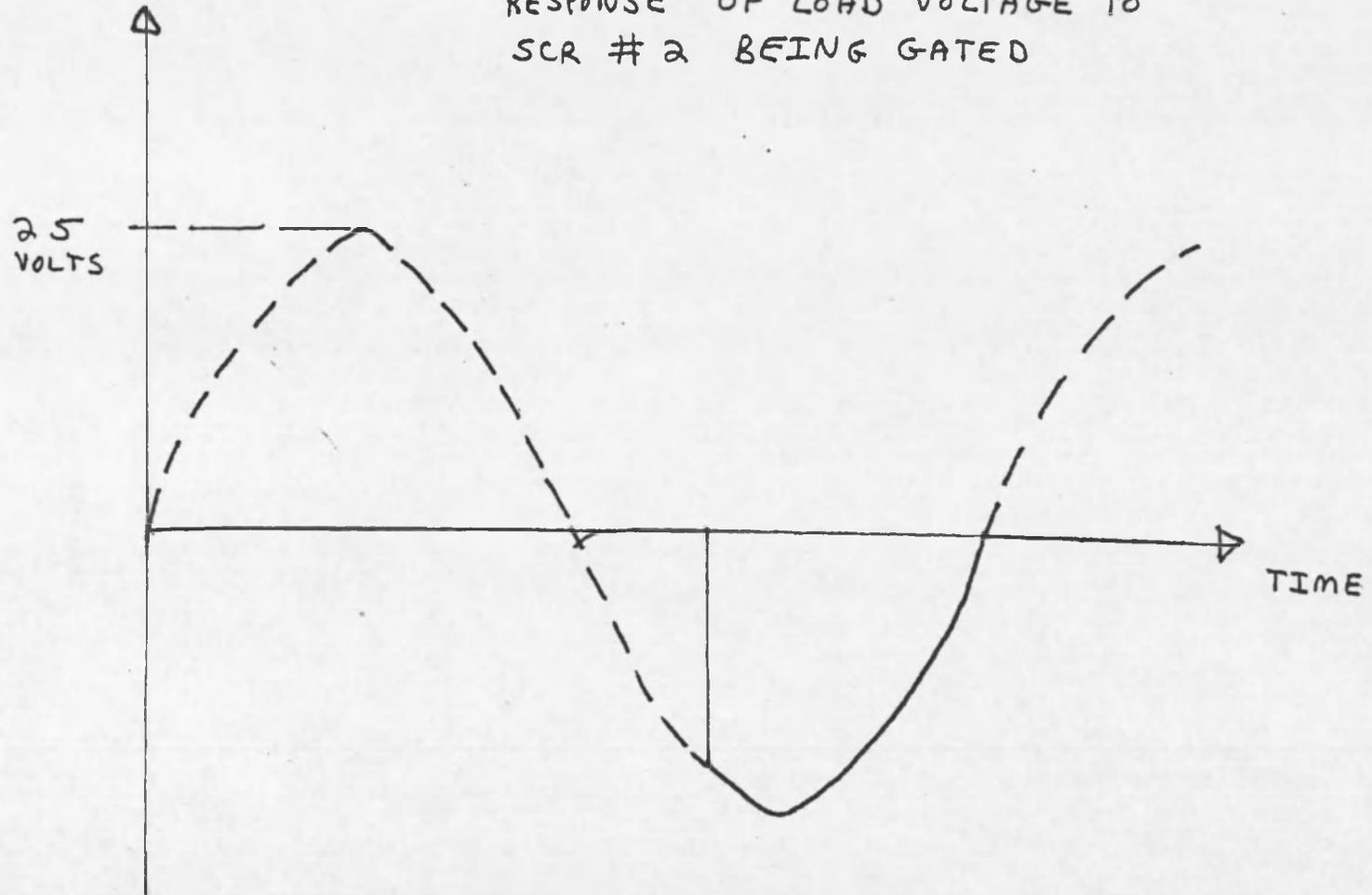


Figure 4.6. Phase control firing of SCR #2.

## CHAPTER 5

### ELECTRICAL CONNECTIONS

The roving vacuum cleaner was controlled from a remote location via a 20 foot long ribbon cable. The cable connected the control potentiometer and slide switch located on the control box to the roving platform which contained the vacuum cleaner, turning motor, and motorized wheel. Figure 5.1 shows the electrical diagram for the roving platform.

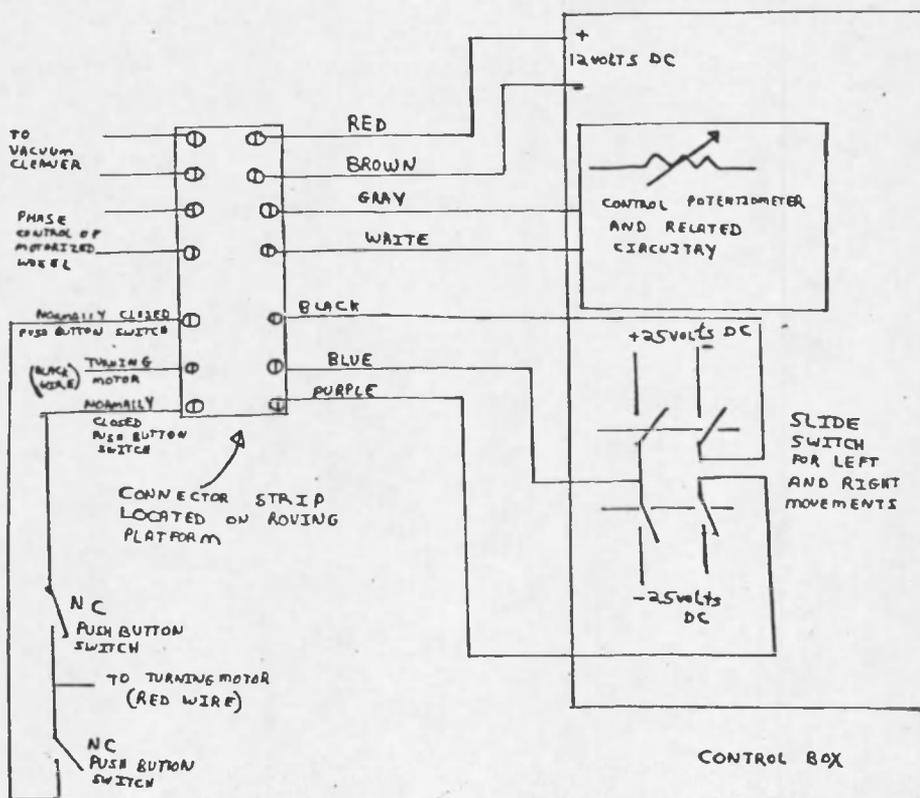


Figure 5.1. Electrical diagram showing ribbon cable interface between the control box and roving platform.

## CHAPTER 6

### EVALUATION OF THE MANEUVERABLE VACUUM CLEANER

The maneuverable vacuum cleaner performed the functions for which it was designed. An operator may sit several feet from the platform while controlling its movement by pushing a slide switch and turning a control knob. If the maneuverable vacuum cleaner should get stuck against an obstruction such as a wall, the motorized wheel would attempt to turn. No damage would result to the roving platform or control circuitry. Several areas exist which must be studied further before the maneuverable vacuum cleaner may be taken out of the laboratory and into the home.

First, a more powerful vacuum cleaner is desirable. If a suction could be created over a larger area, there would be less wasted movement of the platform. A faster cleaning time would result. At the present stage of design, the maneuverable vacuum cleaner utilizes a direct current vacuum cleaner. An alternating current cleaner would be more powerful compared to its direct current counterpart.

Second, weight distribution was not spread out evenly over the roving platform. Unequal amounts of drag

were supplied to each caster. This resulted in more frequent course corrections since the platform gradually deviates from a straight path.

Finally, tests should be performed using handicapped persons as operators. This would determine the extent to which the design of the platform and control box must be modified.

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