Conference Paper

A PROGRESS REPORT

ON

SOLID STATE APPLIANCE CONTROLS

John E. Mungenast

Member IEEE

Manager - Market Development
GENERAL ELECTRIC COMPANY
Semiconductor Products Department
Auburn, New York

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INTRODUCTION

In the last three years several papers have been presented at IEEE seminars discussing new devices and circuits for solid state controls for appliances. This paper will supplement these by examining results to date, investigating assembly procedures, and discussing the all important subject of Merchandising. The latter takes into account the increasing role of the appliance engineer in the product innovation and merchandising decisions necessary for survival in one of the most demanding and fascinating businesses known.

RESULTS TO DATE

First, a question of definition: this paper will deal with all semiconductor usage in the "consumer" area which will consist of major appliances, traffic appliances, lamp dimmers, hand tools, but will except home entertainment electronics such as radio, television, hi fi, etc. It will also include several automotive circuits that have considerable bearing on the consumer area.

Typical consumer/appliance items utilizing solid state components:

- Electronic (microwave) cooking
- Carrier current remote lamp control
- Flame detector
- Frost detector
- Gas Igniter
- Dryness controls
- Condensor fan speed control
- Cordless Clocks
- Electrostatic air cleaners
- Compressor overtemp. protectors
- Time delay relays
- Staple driver controls
- Variable speed blower control
- Remote air conditioner control
- Vacuum cleaner motor speed control
- Electronic oven power supply
- Washer speed control
- Ice harvestor control
- Floor polisher speed control
- Electric knife motor supply
- Battery chargers for cordless devices
- Tool speed controls
- Wall lamp dimmers
- Table lamp dimmers
- Electric heat controls
- Electric car speed control
- Automotive air conditioner thermostat
- Variable height gas flame control
- Solid State thermostat
- Variable speed blender

Most of these applications have developed within the past two years. There is no doubt that the trend is increasing as prices decline and as the solid state devices earn their way into appliance applications. Now a look at the future, as we examine both new devices and the fascinating manufacturing processes that make them possible, and then some new circuit approaches.

NEW DEVICES*

Let's consider five relatively new semiconductors typical of the offerings of the industry and we'll also take a look behind the processes that continue to make possible increased quality at lower costs. The devices are:

1. The Triac family of AC semiconductor controls,
2. The economy line transistor, the first of the new generation of semiconductors,
3. The C106 low cost SCR, essentially a higher power version of the epoxy transistor technology,
4. The silicon strain gage, a new sensor still looking for a job, and
5. The Integrated Circuit, or I/C, which promises a small revolution in the more complex semiconductor circuits needed for some appliance applications.

1. THE TRIAC

As many of you know, the SCR is essentially a half-wave AC control device. In order to control full-wave AC it was necessary to use two SCR's, or one SCR in the heart of a full-wave rectifier bridge. The Triac simplified the AC circuit drastically (illustration #1) while offering protection from transient voltage damage to the semiconductor. The Triac is also of interest in that it is one of the first power semiconductor applications of the Integrated Circuit, to be discussed later, for the functions of several components have been combined into one semiconductor.

2. THE ECONOMY EPOXY TRANSISTOR

The Economy Epoxy Transistor, now widely used in automobile radios, organs, and being designed into appliance controls, was the first high volume semidonductor control device to be successfully fabricated without the expensive glass-metal hermetic seal. The innovation was made possible by two techniques known as the planar method of construction in which the otherwise moisture sensitive silicon is hermetically sealed under a layer of silicon oxide. (Illustration #2.) An expoxy housing is added for mechanical support and protection and for heat dissipation and an additional moisture barrier.

The success of tens of millions of these devices in the severe environments of automotive applications leads to the consideration of this technique for a higher power device such as the SCR.

* A brief review of semiconductor device characteristics is given as Illustration #17.

3. THE C106 LOW COST EPOXY SCR

The C106 Low Cost Epoxy SCR is the result. (Illustration #3.) The planar construction techniques make possible the precise, simultaneous manufacture of many semiconductors in each batch, while the passivation again allows the economies of epoxy protection. This in turn allows great flexibility of mounting and heatsink configurations (Illustration #4).

Also the new technology makes possible a very sensitive SCR, - less than one-fifth of a milliwatt of trigger power is needed to control over 100 watts of load power - and for high quantity prices ranging from 35 cents to 50 cents. There is no other device in control technology that can approach this power control gain, particularly at this very low cost. This gain makes possible many control circuits utilizing low level sensors such as cadmium sulfide photoresistors, thermistors, etc.

4. THE SILICON STRAIN GAGE

The Silicon Strain Gage, still in its infancy, is basically a piezo resistive device whereby resistance varies with tension or compression. The output signal is 50 to 100 times greater than the conventional wire strain gage while size is much smaller as shown in Illustration #5. Projected costs are low enough to warrant attention for many consumer and appliance applications requiring pressure measurements, weight measurements, or the use of a strain gage as a variable resistor, such as a squeeze trigger control for a tool, a foot pedal or knee control for a sewing machine, etc. Most of the devices now being planned have a practical variation of ±15% from a base resistivity which is more than enough to effect the necessary output control when used with the high gain circuits made possible by devices such as the C106. The silicon strain gage is now being used in such applications as yacht and sailboat knotmeters, versus hi-fi phonograph pickups, and medical electronic/space research measurement tools.

5. THE INTEGRATED CIRCUIT

The Integrated Circuit offers an answer to a frequent dilema of the consumer-appliance designer. Many of the most promising solid state circuits require a wide variety of components, resistors, capacitors, diodes, zeners, transistors, often being needed to control the power Triac or SCR. While these parts continue to decline in price, even the mounting and interconnection costs are sometimes enough to rule out use of solid state. The Integrated Circuit is essentially a method of combining certain passive components such as resistors, small capacitors and inter-connections on the same silicon pellet that forms the transistors, diodes, etc. Illustration #6 shows a simple audio amplifier in its vacuum tube form, a transistorized circuit, and then the integrated circuit. Illustration #7 is a greatly enlarged view and shows the actual size of the integrated circuit assembly.

While Integrated Circuits received their first acceptance from the military and space markets because of size reduction, and then from the industrial computer market for reliability, they will someday find a niche in the appliance market because they are the least expensive way of building many types of circuit.

But tooling and design costs are very high so the Integrated Circuit will generally be considered only after the market and the application has been thoroughly tested by means of circuitry using conventional devices and when high volume is assured.

NEW CIRCUITS

While the star of our show is the family of new devices described before, some new circuits have come along that should be of interest. Let's start with those centered around the new low cost C106 epoxy SCR. (Illustration #8). These circuits feature relative simplicity and lower cost because the great sensitivity of the low cost SCR reduces the wattage dissipation, therefore the size and the cost of the firing circuits components.

AC motor speed controls are another item of deepening interest as motor manufacturers and semiconductor control manufacturers learn to work together with the customer to optimize various motor design and semiconductor design parameters. Certainly the most significant example is the new Hotpoint continuously variable washer speed control featuring a special motor built by the General Electric Appliance Motor Department, DeKalb, Ill., and a control module built by GE Appliance Control Department, Morrison, Ill. The basic circuit is shown in the Illustration #9. Note that the system is variable voltage, rather than variable frequency as is the case in most industrial induction motor speed controls. It is essentially the equivalent of an eddy current clutch, allowing the motor to slip and holding at the desired speed by means of an inexpensive tachometer built integrally with the motor. The control and firing circuit is mounted behind the back splash and is shown in photograph #10.

The appliance engineer can take pride in the fact that this advanced motor and control concept appears in a home appliance long before general acceptance in commercial or industrial drive systems. In the past solid state control systems have generally found their acceptance in military applications first, then industrial and commercial circuitry, finally filtering down to the consumer market. In the last few years, as the appliance engineer has learned to work with solid state, we find more examples of basic new concepts emerging first in the consumer-appliance market.

The variable speed AC concept is also creating interest in the home furnace or central air conditioning market as a means of varying the blower speed based on duct temperature or other variables. The basic principle here is the CAC (continuous air circulation) long discussed as the ideal means of even heat distribution throughout the home. The disadvantages of high noise level and cold drafts are minimized by an adjustable speed such as the one built by GE Appliance Control, Morrison (Illustration #11) which works as follows:

1. The blower is continuously activated, running at very low speeds most of the time with delivery just sufficient to avoid stratification of the air layers, preventing what is known as "cold toes - hot nose" effect.

2. When the thermostat signals for heat, the ducts warm up and the blower increases speed. The continuous circulation also provides a better air sample for the thermostat, particularly in multi-level homes with long duct runs.

OTHER HEATING-COOLING APPLICATIONS

Solid state systems for gas flame modulation have been offered for years, and electronic thermostats using thermistors have also been tried in the past. However, the most advanced thermostat concept is probably that utilized in the new automotive air conditioning/heating "comfort controls". These circuits utilize thermistors and solid state amplifiers, along with electromechanical hybrid circuits to accomplish both choice and degree of heating/cooling.

(Illustration #12.) Note how the solid state sensing and amplifier circuit makes simple provision for multiple sensing, from either indoor/outdoor or several indoor positions or variations of both. The weighting of these temperatures can be easily adjusted by trimming various resistance values within the bridge.

THE HYBRID MECHANICAL-SOLID STATE TEMPERATURE CONTROL

The automotive temperature control is an excellent example of one family of "hybrid" control, namely those utilizing solid state sensing and electromechanical actuation, either because solid state cannot accomplish the function or can only accomplish the function (such as switching many kilowatts) at much higher cost.

A second family of hybrid switching utilizes electromechanical sensing and solid state amplification. It is based on the premise that many functions can be better accomplished with sophisticated electromechanical devices such as bi-metallic elements for temperature, nylon threads for humidity, etc. These devices can often be optimized when they need handle only control power for the semicondictor and not called upon to switch large electrical loads at high repetition rates. Thus Illustration #13 shows both an on-off and a modulating hybrid concept using solid state power control. In the first case the solid state Triac is used to amplify a low level signal from the bi-metallic contacts, in the second case the solid state photo resistive cell is used to convert the rotation of the disk caused by a humidity sensitive nylon strip into a change of resistance. This varying resistance then modulates output load power through the SCR or Triac, the shape of the aperture determining input/output characteristics.

SYNCHRONOUS SWITCHING

While hybrid controls are now used for most high power electrical loads such as electric heating, dryer heating elements, ranges, ovens, etc., at some time in the future the solid state power switches will certainly drop in price to where they might be attractive here. However, the high costs of RFI (radio frequency interference) filtering circuitry might still preclude the use of solid state with conventional phase control. Synchronous switching, appears to be the answer whereby power is only controlled at the zero switching point. (Illustration #14.)

CARRIER CURRENT REMOTE CONTROL

Many remote control systems have been proposed for remote actuation of air conditioners, signalling at end of drying or oven cycles, etc. Ultrasonic sound systems are presently used for television set operation but the carrier current concept has considerable appeal for any control scheme to be used within the home. The basic principles of such a circuit are outlined in Illustration #15 which shows the transmitter and receiver synchronized by the sine-wave. Several commercial systems use this concept for actuation of lamps, transmission of hi-fi music or intercom operation within the house. This system has merit, for remote control of thermostat or air conditioning blower speed from bedside or any point in the house where you wish to control temperature.

NEW TRENDS IN SERIES MOTOR TOOL CONTROLS

Perhaps one of the most interesting new consumer applications of solid state is the squeeze-trigger tool speed control. Illustration #16 shows a cut-away view of a typical speed control showing the SCR element, the neon firing circuit, the variable resistance and switching contacts. This control is an excellent example of a completely integrated control wherein several functions have been combined and optimized around solid state technologies.

ELECTRONIC ASSEMBLY TECHNIQUES FOR THE APPLIANCE ENGINEER

As the appliance engineer attempts to assist manufacturing engineering deeper into electronic assembly he finds a considerable difference of opinion on the best way of assembling various components needed to do a practical control job. This paper will certainly not attempt a definitive answer, but our experience in building assemblies and sub-assemblies for many consumer-appliance customers has taught us the following:

1. While electronic assemblies can definitely be built at lower tooling costs than mechanical controls, don't overlook the skills in manufacturing engineering, production, inspection, quality control, procurement, etc., necessary to build consistent quality, high volume electronic sub-assemblies.

2. Hand-wired sub-assemblies have the lowest fixed cost and offer a very simple way of attempting small prototype quantities, but high volume electronic assembly the world over has generally chosen the printed circuit board as the best single approach.

3. The printed circuit board is a simple concept, but it must be done right. This involves the correct component choice and dimension before tooling the board, mechanized soldering facilities, and attention to detail on the flux, solder, inspection, etc.

4. The electronic component market will seem like an Oriental bazaar to your materials procurement people. It is important to deal with vendors that you trust who can help explain the many choices possible between resistors, capacitors, potentiometers, semiconductors, etc.

5. Allow sufficient time for Underwriter Laboratory familiarization with your new control concept. A good many solid state devices have gained UL approval and are in wide use. But each new application poses a slightly different problem and UL is obligated to re-examine the system concept from the bottom up. Your semiconductor supplier or appliance control manufacturer can often advise you of some possible pitfalls to be avoided here.

THE MERCHANDISING ASPECTS OF SOLID STATE APPLIANCE CONTROLS

Such a discussion might, at first glance, seem somewhat out of place in the technical presentation. But the facts of life are that few of the innovations mentioned here cost less, or ever will cost less than the simplest electromechanical control. In some cases they do a better job, or do things hiterto impossible. In other cases they will have that undeniable glamour of Solid State, or Transistorization, that might capture the public's imagination even if they don't accomplish earth shattering objectives. But in any event they will have to be merchandized.

And in many cases it must fall to the design engineer to remind the product planner or the merchandising influences within his company of the proven attraction of solid state from the customer's point of view. This salability seems to result from several attributes:

1. The very terms "solid state, transistorized, and electronics" are identified in the public mind with progress, innovation, low maintenance, and economy.

2. Transistors have tens of millions of good will ambassadors, in the form of the ubiquitous transistor radios, one at each ear of every teenager, it seems. These radios have done an excellent job in spreading the word about what can be expected from transistorized or solid state controls.

3. Solid state has made a good number of features possible, among them the rechargeable cordless appliance, the variable speed tool, the automotive alternator, the home laundry dryness control, etc. Thus there is a natural inference that "Solid State means Innovation." So powerful is this image that on several products solid state has been added only for merchandising reasons, with rather sizeable price increases, and the resulting sales have surprised both the manufacturer and the retailers.

Other merchandising principles to keep in mind:

1. Be cautious in judging the salability of a new concept - remember the two speed washer, the electric can opener, knife, and toothbrush. The important factor is getting the concept market tested at reasonably low cost, and here the low tooling costs of solid state can offer great flexibility.

2. A new feature only costs money when it <u>doesn't</u> help sell the appliance at a profit. Let's take a lead from the auto manufacturers who judge new features not by cost, but by <u>value</u> in selling the car.

Solid state controls not only open new ways of more effective control, they help create new end products, but most important -

SOLID STATE SELLS!

* * * * *

Acknowledgements

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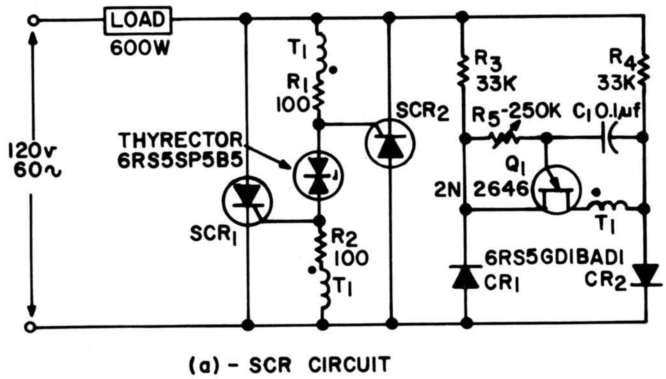
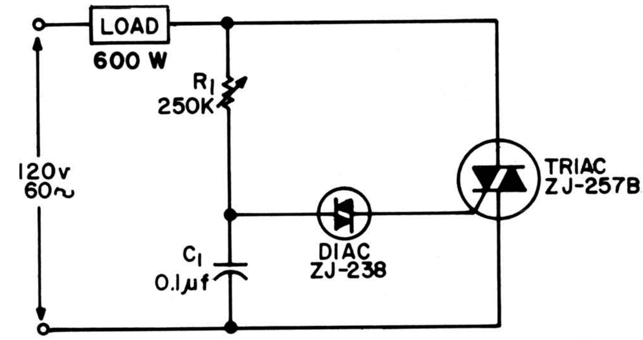


(a) SCR Circuit



(b) Triac Circuit

Illustration 1. Basic Full-Wave Phase Control Circuits

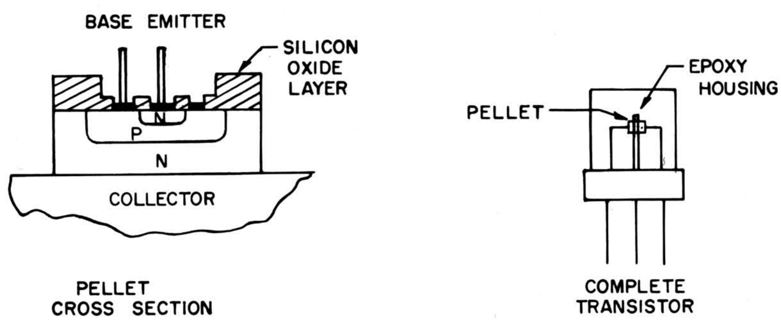
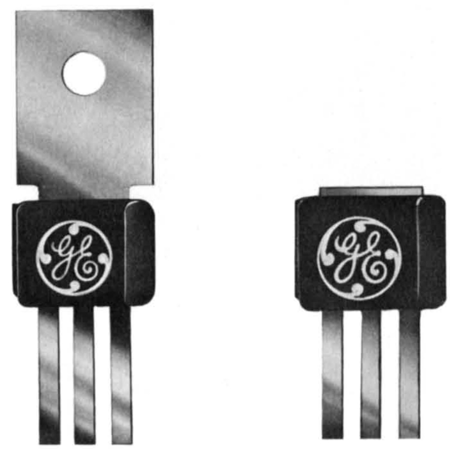


Illustration 2. Planar Passivated Construction Techniques



C106 TYPE 1 C106 TYPE 2

Illustration 3. Low Cost Epoxy SCR

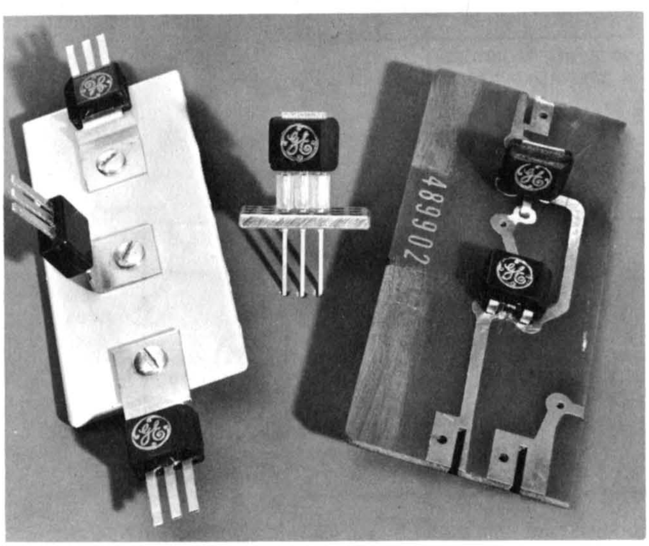


Illustration 4. Epoxy SCR Mounting and Heatsink Configurations

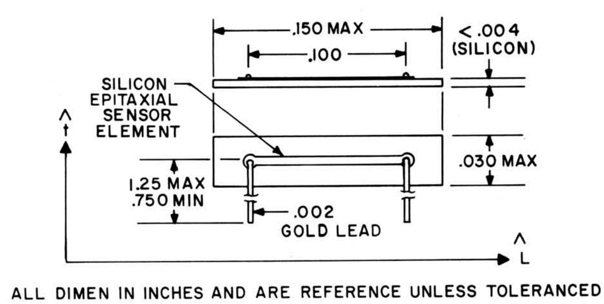


Illustration 5. Silicon Strain Gage

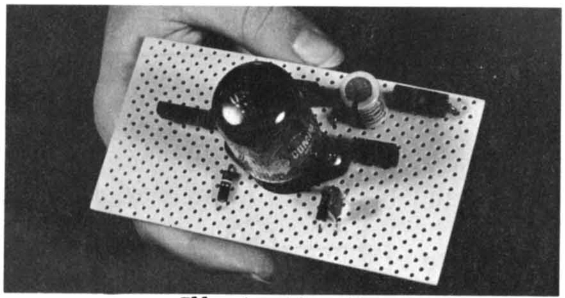


Illustration 6a.
Vacuum Tube Audio Amplifier

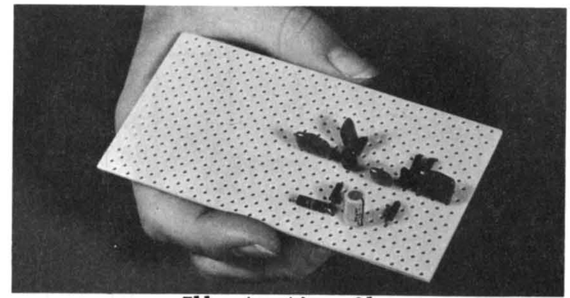


Illustration 6b.
Transistorized Audio Amplifier

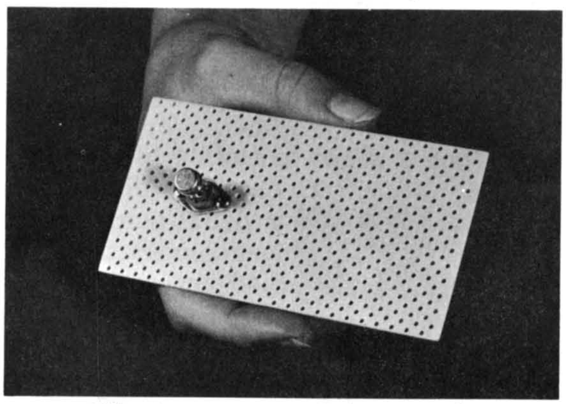


Illustration 6c. Integrated Circuit Audio Amplifier

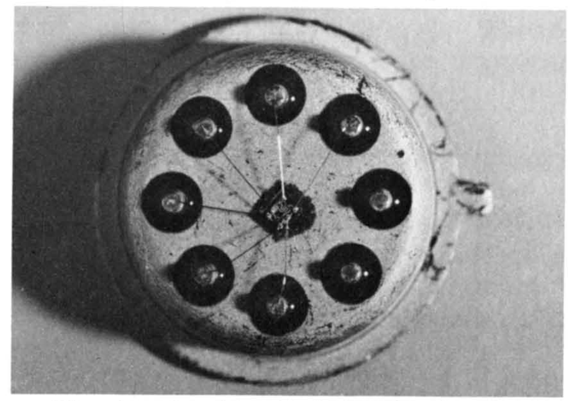
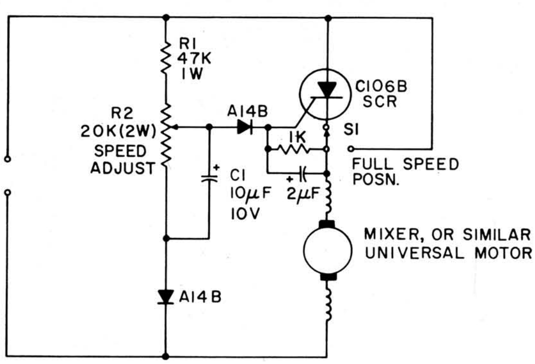
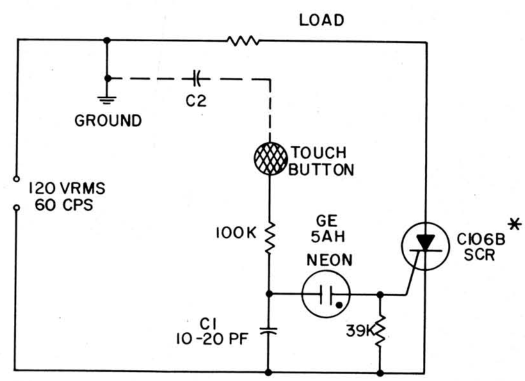


Illustration 7. Enlarged View of Integrated Circuit Audio Amplifier



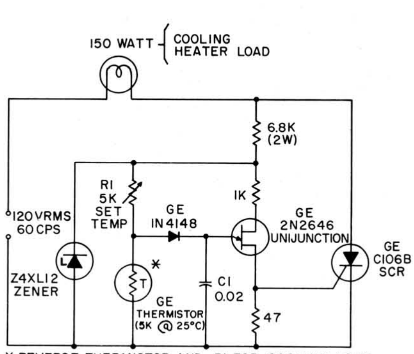
NOTE: RESISTORS 1/2 WATT EXCEPT AS NOTED

Illustration 8a. Universal Motor Speed Control



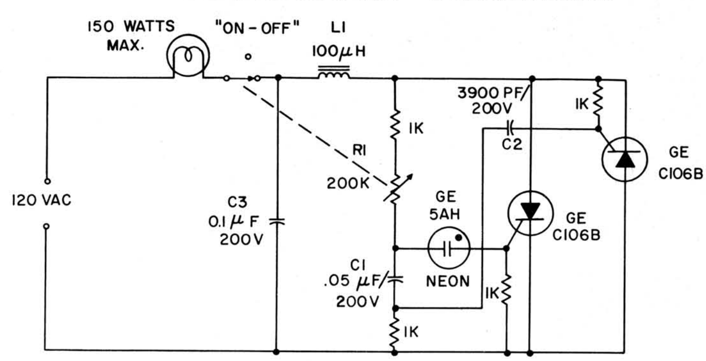
NOTE: ALL RESISTORS 1/2 WATT
* SPECIAL— CONTACT FACTORY

Illustration 8b. Touch Switch



* REVERSE THERMISTOR AND R1 FOR COOLING LOAD
NOTE: ALL RESISTORS 1/2 WATT EXCEPT AS NOTED

Illustration 8c. Temperature Controller



NOTE: ALL RESISTORS 1/4 WATT (OR 1/2 WATT IF SIZE NOT IMPORTANT)

Illustration 8d. Low Cost Brightness Control

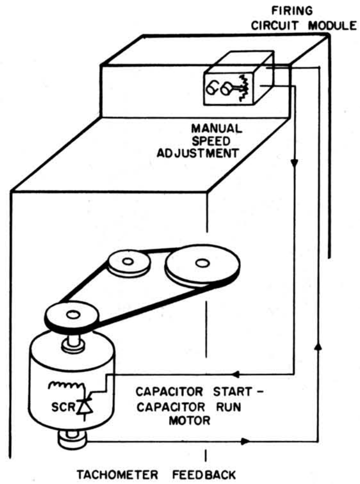


Illustration 9. Continuously Variable Speed Washer Drive

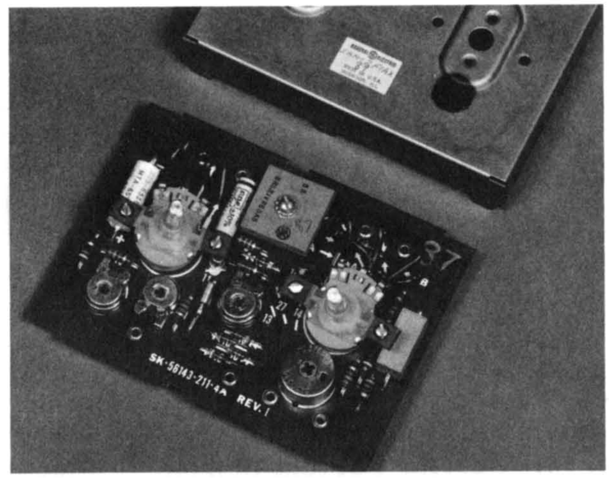


Illustration 10. Control and Firing Circuit

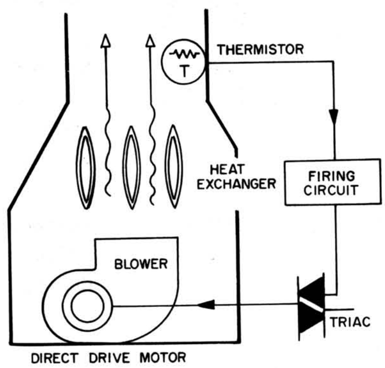


Illustration 11. Furnace Blower Speed Control

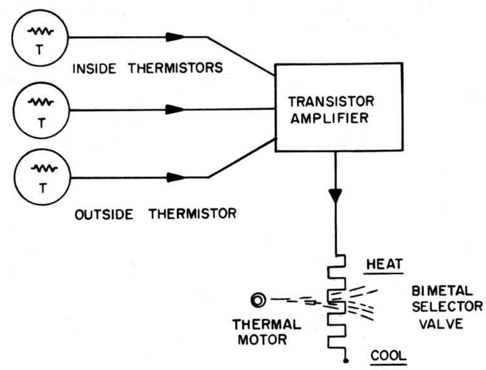


Illustration 12. Electronic Thermostat for Automotive Heating/Air Conditioning Control

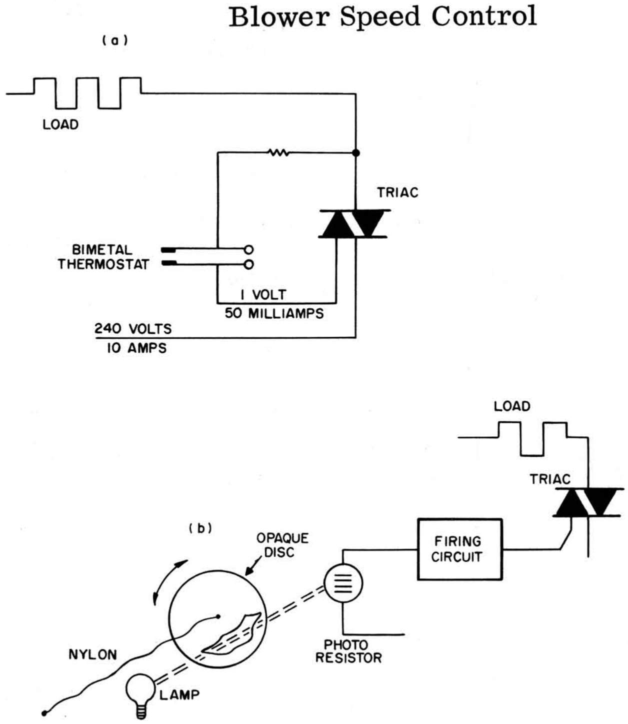


Illustration 13. Hybrid Control Concepts

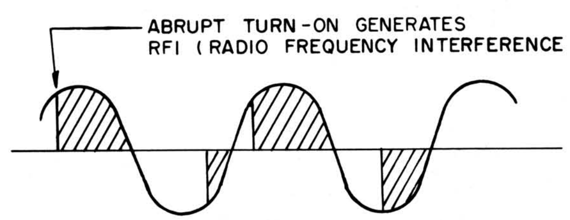


Illustration 14a. Conventional Phase Control

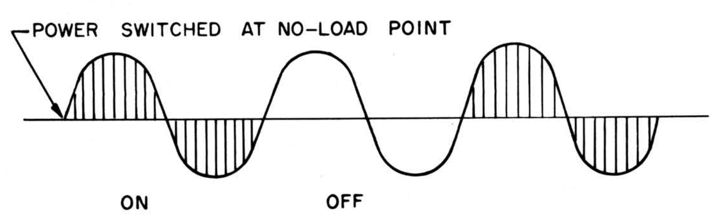


Illustration 14b. Conventional Phase Control with Synchronous Switching Firing Circuitry

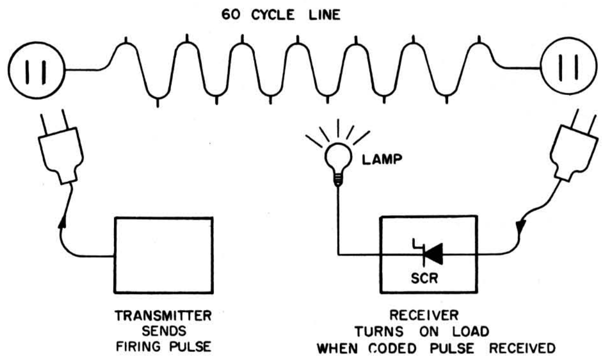


Illustration 15. Carrier Current Remote Control System

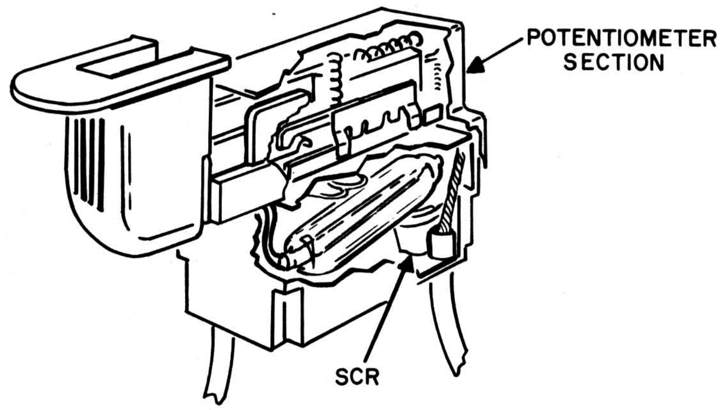


Illustration 16. Trigger Speed Control Utilizing SCR and Neon Lamp Firing Circuit

Name of Device	Circuit Symbol	Commonly Used Junction Schematic	Electrical Characteristics	Max Ratings Available From G. E.	Major Applications	Roughly Analogous To:
Diode or Rectifier	ANODE, CATHODE	ANODE, p, n, CATHODE	Conducts easily in one direction, blocks in the other	500 Amps 1500 Volts	Rectification Blocking Detecting Steering	Check valve Diode tube Gas diode
Avalanche (Zener) Diode	ANODE, CATHODE	ANODE, p, n, CATHODE	Constant voltage characteristic in negative quadrant	22 Volts 1 Watt	Regulation Reference Clipping	V-R tube
n-p-n Transistor	COLLECTOR, BASE, EMITTER, I_B	COLLECTOR, n, p, n, BASE, EMITTER	Constant collector current for given base drive	200 Volts 60 Watts	Amplification Switching Oscillation	Pentode Tube
Silicon Controlled Rectifier (SCR)	ANODE, GATE, CATHODE	ANODE, p, n, p, n, CATHODE, I_g, GATE	With anode voltage (+), SCR can be triggered by I_g, remaining in conduction until anode I is reduced to zero	300 Amps 1300 Volts	Power switching Phase control Inverters Choppers	Gas thyratron or ignitron
Triac	ANODE 2, GATE, ANODE 1	ANODE 2, n, p, n, n, n, p, GATE, ANODE 1	Operates similar to SCR except can be triggered into conduction in either direction by (+) or (—) gate signal	10 Amps 400 Volts	AC switching Phase control Relay replacement	Two SCR's in inverse parallel

Illustration 17. Major Semiconductor Components