Chapter 4

SEMICONDUCTORS

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Introduction

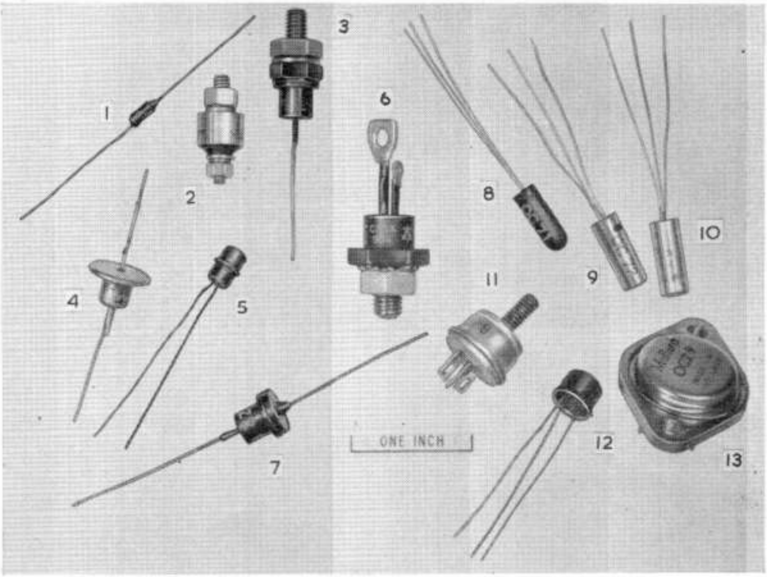
1. This chapter is intended to be an introduction to the basic principles of semiconductors, their applications and operational limitations and to the precautions to be observed during the servicing of equipment in which they are used.

DESCRIPTION

2. Semiconductors are neither good conductors nor good insulators and their resistance varies inversely with temperature. Germanium and silicon are semiconductors used in the manufacture of diodes and transistors which are incorporated in voltage regulators, inverters, d.c. converters and a wide range of electronic equipment.

Germanium

3. Germanium is a greyish white metallic element which is found in a few rare metals and is also obtained as an oxide from the ash of burnt coal. Each atom of germanium has a nucleus and a number of tightly bound electrons with four orbiting valence electrons which form covalent bonds with the valence



1 SILICON RECTIFIER (*Glass seal*), TYPE 1S113
2 GERMANIUM RECTIFIER, TYPE GJ5.M
3 SILICON RECTIFIER, TYPE ZR.22
4 ZENER DIODE, TYPE VR.625
5 SILICON DIODE, TYPE CV.4073
6 SILICON CONTROLLED RECTIFIER, TYPE C.35A
7 SILICON RECTIFIER, TYPE ZR.12
8 GERMANIUM TRANSISTOR, TYPE OC.71
9 GERMANIUM TRANSISTOR, TYPE OC.72
10 GERMANIUM TRANSISTOR, TYPE CV.7007
11 GERMANIUM TRANSISTOR, TYPE H6
12 SILICON TRANSISTOR, TYPE 2S003
13 GERMANIUM TRANSISTOR, TYPE OC.29

Fig. 1 Semiconductors

electrons of neighbouring atoms. In a single germanium crystal the atoms are equidistant and are arranged in a regular pattern known as a lattice structure.

4. Pure germanium is almost an insulator because the orbital electrons of each of its atoms form covalent bonds with the valence electrons of other atoms and are not available as charge carriers unless the bonds are broken by the application of external energy in the form of light or heat.

5. The conductivity of germanium is improved, whilst still retaining the lattice structure of the crystal, by the introduction of very low percentages of pentavalent atoms such as antimony or arsenic and trivalent atoms such as indium or boron. Four of the pentavalent atom's orbital electrons form covalent bonds with germanium atoms but the fifth is free to move through the crystal as a negative charge carrier. The impurity atom which provided the electron is termed a 'donor' and the adulterated germanium is known as 'N' type because the current flowing through it is due to electrons.

6. All the trivalent atoms' orbital electrons form covalent bonds with the electrons of neighbouring germanium atoms in the crystal lattice, and each leaves a vacancy or 'hole' to be filled by a fourth electron. The orbiting electron filling the hole will leave a hole in a different atom to be filled by a further electron and the process will continue so as to produce an apparent movement of holes through the crystal. Impurity atoms which receive electrons are called 'acceptors' and the adulterated germanium is known as 'P' type because the holes are positive charge carriers.

7. 'P' type material has a majority of holes whilst in 'N' type material electrons predominate due to the donor and the acceptor atoms respectively. These majority carriers do not cause the minority carriers to completely disappear because pairs of holes and electrons are continually being generated by thermal agitation. Thermally generated electrons in 'N' type material have little effect on the large concentration of majority carriers but the minority carriers have a very short life before they combine with electrons.

8. A germanium crystal at room temperature is an intrinsic semiconductor in which conduction is by thermally produced holes and electrons, which move towards opposite poles of an applied potential but carry a unidirectional current. This current is of a low value because the number of holes and electrons is a very small percentage of the total number of atoms in the crystal. Mobile carriers produced by the introduction of extremely small concentrations of impurity atoms are considerably in excess of those produced by thermal ionisation.

Silicon

9. Silicon is a grey non-metallic element and is the main constituent of many clays, rocks and soils; it is manufactured by the reduction of silica with carbon at high temperature. Each atom of silicon has 14 tightly bound electrons and 4 valence electrons in orbit around its nucleus. In operation it is similar to germanium but will function at higher temperatures and also differs in other characteristics such as frequency response and voltage and current ratings.

Junction diodes

10. Junction diodes are crystals, usually of germanium or silicon, having two regions, one of 'P' type and one of 'N' type materials. The transition from one region to the other is termed the junction across which the crystal lattice is continuous. Such a junction may be formed by the fusion of material having donor impurities into a crystal having acceptor impurities.

11. Without any potential being applied, electrons begin to diffuse from the 'N' region across the junction and holes move in the opposite direction to the 'N' region. This initial movement of carriers causes the 'P' material to become negatively charged in the region of the junction and the 'N' material to become positively charged thus setting up an effective potential barrier which prevents further carrier movement.

12. A potential applied to the junction in the forward direction, i.e. with the positive terminal connected to the 'P' material, will cause a steady flow of current at normal room temperatures, by both electrons and holes. Increasing the applied potential in the forward direction will cause the current to rise rapidly with a negligible voltage drop across the diode. The maximum permissible forward current is limited by temperature considerations.

13. Application of a potential across the diode in the reverse direction will result in a very small current flow because of the small number of holes in the 'N' material to be attracted to the positive side of the potential and the negligible quantity of free electrons to be attracted from the 'P' region to the opposite side of the potential. The application of higher reverse potentials, up to the rated maximum, has very little effect on the current value. When however the maximum reverse voltage is exceeded and a voltage known as the 'turnover' point is reached, the current rises steeply and its value is limited only by the resistance connected in series with the diode. The voltage, however, remains constant across the diode, further increases in the applied potential affecting only the current.

14. Germanium diodes have a low forward voltage drop, moderate reverse current ratings and low maximum permissible junction temperatures. Silicon diodes have a higher maximum permissible junction temperature, a larger forward voltage drop and higher reverse voltage ratings with lower reverse current. Excessive overloading of either type of diode can cause thermal instability and subsequent failure. The low thermal mass of the semiconductor wafer limits the overload capacity and may in some applications necessitate special protective measures such as high-speed fuses or over-current relays.

Zener diodes

15. Zener diodes are silicon junction diodes in which relatively high percentages of impurities are introduced to the P and N materials during manufacture to obtain a sharp break in the relationship between the reverse voltage and the reverse current. They are designed to carry relatively high reverse currents and to have a slope resistance of the reverse characteristic which falls to an extremely low value at a critical reverse (Zener) voltage. Beyond this point the potential across the diode remains constant within close limits but the current rises steeply with increased voltage.

16. Zener diodes have a normal forward current characteristic and they can therefore be used as ordinary diodes. The constant low reverse current between zero and the turnover point is utilized when the diode is used as a rectifier; the constant voltage between the turnover point and the maximum current determined by temperature considerations is utilized in voltage regulation, stabilization and similar applications.

Transistors

General

17. The transistor is a semiconductor device that can be used as an amplifier, an oscillator or as a switch. There are two types of transistor, the point contact and the junction type. The former has two pointed electrodes, positioned very close together, which make contact with a thin wafer of germanium. The point contact transistor has been largely superseded by the junction type which may be made from either germanium or silicon and, besides having an improved performance, is easier to manufacture and less liable to damage.

Junction transistors

18. The junction transistor comprises a thin wafer of semiconductor material having two p–n junctions separating three regions in the same crystal. The regions may be arranged in either the p–n–p or n–p–n formation, the centre region being termed the base and the two outer regions being known as the emitter and the collector respectively. The base wafer is made very thin and the collector-base junction is larger than that of the emitter to allow the maximum number of majority carriers to diffuse through the base to the collector region so as to increase the current gain of the transistor. The thin base also improves the operation of the transistor at higher frequencies.

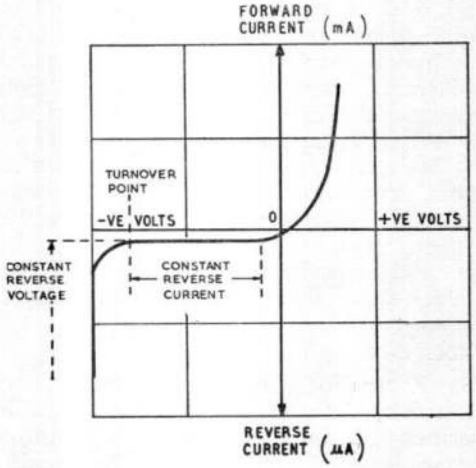


Fig. 2 Junction diode characteristics

19. Electrodes are attached to each of the three regions during manufacture in a manner which provides a low resistance, non-rectifying contact and the assembly is hermetically sealed in a glass or metal container. The protruding terminal wires may usually be identified by the base wire being positioned between the other two, and the collector having an adjacent spot of paint or being further from the base wire than is the emitter lead. In power transistors the metal case forms the collector connection and may also serve as a heat shunt, the emitter and base electrodes terminating in insulated pins to which soldered connections can be made.

20. The junction transistor may be considered as comprising two junction diodes arranged back to back with the two common regions forming the base. One of the junctions offers a low resistance to an input current whilst the second junction forms an output circuit of relatively high impedance. When connected into a circuit, the p-n-p transistor is usually biased so that the emitter is positive to the base whilst the collector is biased in the reverse direction (The polarities are reversed with n-p-n transistors).

21. Fig. 3 shows a method of biasing in which the required base potential is obtained from the centre point of two resistors (R1 and R2) forming a voltage dividing circuit

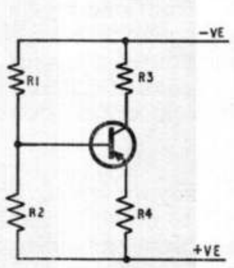


Fig. 3 P-N-P transistor biasing

across the supply lines. The emitter current is determined by the series resistor (R4) and the collector current through the load resistor (R3) is dependent on the current gain between the emitter and the collector.

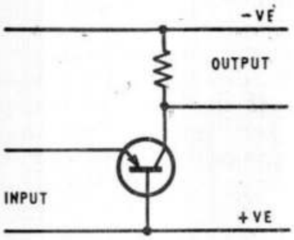
22. In the p–n–p transistor the forward-biased emitter region emits holes into the base region, the majority of which are attracted to the negative biased collector region, only a very small proportion recombine with electrons in the base region. This flow of holes from the emitter to the collector constitutes the main current and is the basis of transistor action in the p–n–p transistor. There is also a small current in the reverse direction due to electrons in the p type material which are known as minority carriers because of their small number in comparison with the holes or majority carriers. In the n–p–n transistor electrons are the majority carriers and constitute the main current through the transistor whilst the reverse current is carried by electrons.

Circuit arrangement

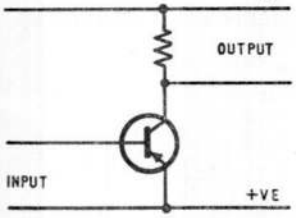
23. A transistor may be connected into a circuit in three different ways which are defined according to the terminal that is common to both input and output circuits in each arrangement. In the common base circuit the current gain is less than unity but there is a better frequency response than in the other arrangements and there is no phase shift between the input and output voltages.

24. In the common emitter arrangement, which is the most frequently used, there is a high current gain but the operating frequency is less than that of the common base mode and there is a 180° phase shift between the input and output voltages.

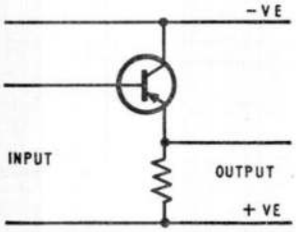
25. Referring to the diagram of a transistor connected in the common base arrangement at fig. 4 (*a*), most of the current through the transistor passes from the emitter to the collector, only about 2% of the total current flows to the base. Thus variations in emitter current cause almost similar changes in collector current; the ratio between the change in collector current due to a given change in emitter current is termed the current gain of the transistor and in the common base mode is 0·98.



(*a*) *Common base*



(*b*) *Common emitter*



(*c*) *Common collector*

Fig. 4 Transistor circuit connections

26. Although the current gain in the common base mode is less than unity, the input current varies in the relatively low resistance of the forward-biased emitter-base junction but the output current changes in the much higher impedance of the collector base junction, there is therefore a power gain because the two currents are almost equal despite the higher impedance of the output circuit.

27. The relationship between the emitter, base and collector currents does not alter with the method of connecting the transistor into a circuit. Therefore a change of base current in a transistor connected in the common emitter arrangement, as in fig. 4 (*b*), will cause a much greater change in the value of the collector current, the current gain approaching 50. There is also a power gain due to the difference in the impedance of the input and output circuits.

Transistor switching circuits

28. Transistors are used in switching circuits in a manner similar to that in which thermionic valves are used; they have a small voltage drop when conducting and a high series resistance when in the non-conducting condition. Switching transistors are small, quiet and reliable and they have a high operating speed. They are connected most commonly in the common emitter mode in which a small base current can control a relatively large collector current.

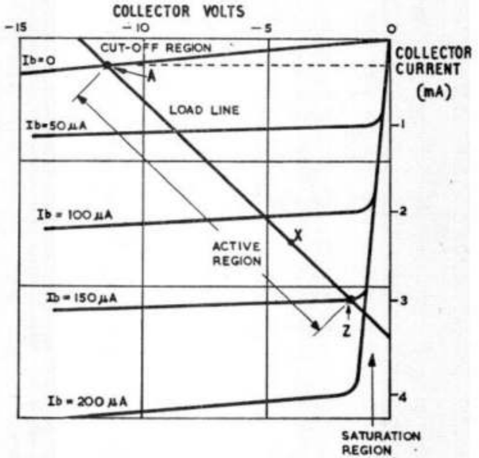


Fig. 5 Switching transistor characteristics

Output characteristics

29. The output characteristics of a switching transistor are non-linear and as shown in fig. 5 are arranged in three regions.

(1) *The cut-off region* in which the transistor is non-conducting, both junctions are reverse-biased so that input and output impedances are high, and the voltage of the collector is almost equal to the supply voltage. This is a stable region of operation.

(2) *The active region* is an unstable region through which the operating point passes in transit from one stable region to the other. It is the only region in which normal amplifier gain is obtained.

(3) *The saturation region* is also a stable region of operation, both junctions being forward biased, the collector current at a maximum and the collector voltage at a minimum. In this region both the input and the output resistances are very low, the base current is high and there is no current gain. A transistor in this region is said to be in the bottomed condition.

30. Referring to fig. 5, at point A on the load line the operating point of the transistor is in the cut off region, there is no base current, the collector voltage is high and the small collector current, indicated by the dashed horizontal line, is the reverse bias collector current. The switch is open, that is there is a high resistance between the emitter and the collector of the transistor.

31. The application of a negative potential or pulse to the transistor base will cause base current to flow and the collector current to rise so that the operating point moves from point A along the load line. If the transistor is being used as a non-saturating switch the base current will drive the collector current to some point such as X on the load line, short of the fully ON position at point Z. When used as a saturating switch a higher base current is required to drive the collector current through the fully ON position where the transistor is in saturation.

32. The saturating switch provides a lower resistance in its ON position but has a longer switching period, particularly when driven far into saturation, due to storage effects caused by the minority carriers (electrons in p–n–p transistors) being accumulated in the base region and subsequently delaying the change in collector current after the base drive has been removed.

33. When the transistor is saturated its collector current is at a maximum determined by the external load resistance and any further increase in the base driving current has no appreciable effect on the collector current value.

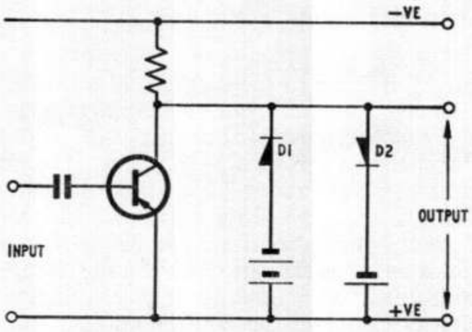


Fig. 6 Clamping diodes

Saturation and cut off clamping

34. The output waveform of switching transistors may be affected adversely if the transistors are operated beyond the saturation or cut off points. Clamping diodes are used to prevent transistor operation beyond these points by clamping the collector potential within values which prevent cut off and saturation respectively.

35. The circuit at fig. 6 shows a p–n–p transistor connected in the common emitter arrangement and using two diodes (D1 and D2) to prevent the base current driving the transistor into the cut off and saturation states respectively.

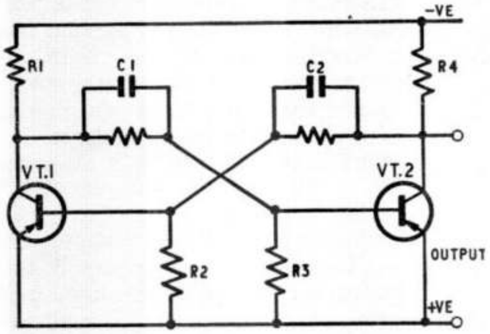
36. When an increasing base driving current causes the collector current to rise, the collector voltage falls from a high to a low value until it reaches the voltage of the D2 bias battery and the diode begins to conduct. The conducting diode has a very low resistance so the collector voltage is clamped effectively at the voltage of the bias battery and therefore is not affected by any further increases in collector current; the transistor is thus prevented from being driven into saturation.

37. During the foregoing operations the diode D1 and its bias battery were not in use since they are concerned only with the cut off collector potential. Similarly the saturation diode D2 is reverse biased by its battery and is effectively an open circuit during the following action.

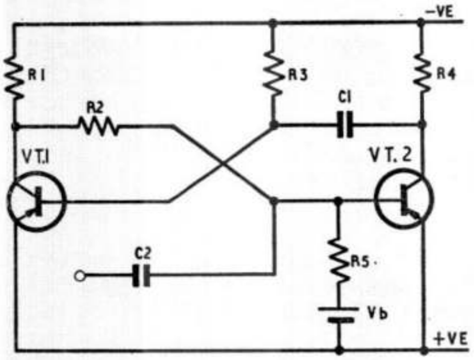
38. As the base driving current falls from its maximum value the collector current decreases and the collector voltage becomes more negative. When it has risen to the voltage of the D1 bias battery the diode (D1) becomes forward biased and conducts; any further decrease in the base driving current has no effect on the collector potential which remains clamped at the bias voltage, thus preventing cut off.

Multivibrator circuits

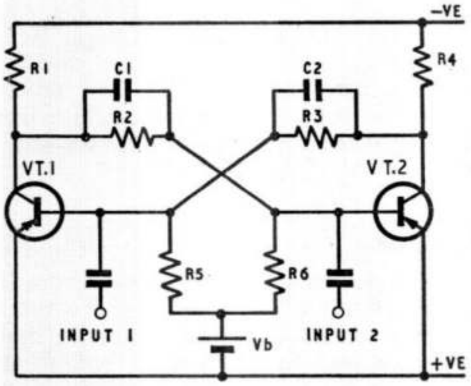
39. In multivibrator circuits an external pulse is applied to initiate a change in their operating states, the action being completed by regenerative action within the circuits. There are three types of multivibrator circuits: Astable, Monostable, and Bistable, their main differences being in the methods of cross-coupling as shown in fig. 7 (*a*), (*b*) and (*c*).



(*a*) *Astable circuit*



(*b*) *Monostable circuit*



(c) *Bistable circuit*

Fig. 7 Multivibrator circuits

Astable circuit

40. The astable or free-running circuit has two stable states in which one transistor conducts whilst the other is cut off for a time period determined by the circuit constants, after which the conditions are reversed. The circuit is self-starting but pulses may be used for frequency synchronization. The emitter-base junctions of the transistors are forward biased and when d.c. power is applied both transistors conduct but due to component variations one takes more current than the other. Regenerative action takes place resulting in one of the transistors being driven into the cut off state whilst the other is saturated.

41. Referring to fig. 7 (*a*) and assuming that transistor VT.1 conducts more heavily than VT.2, its collector voltage will become more positive as the current increases. This positive going potential is coupled by the capacitor C.1 to the base of VT.2 and has the effect of reducing the collector current of that transistor. As the VT.2 collector current falls its voltage rises, that is it becomes more negative, and through the coupling capacitor C2 it is applied to the base of VT.1 to increase the forward bias of the transistor. This regenerative action continues until VT.1 is fully on, or saturated, and VT.2 is cut off.

42. The collector current and voltage of VT.1 remain constant for a period and the capacitor C1 discharges through its resistor reducing the reverse bias on the base of VT.2, until forward bias is re-established and the transistor conducts. Regenerative action takes place in a manner similar to that described in the previous paragraph until VT.2 is saturated and VT.1 is cut off. Transistor VT.2 remains fully on whilst capacitor C2 discharges through its resistor sufficiently to remove the reverse bias from VT.1 when the transistor begins to conduct and the cycle of operations is then repeated.

Monostable circuit

43. The monostable circuit differs from the astable circuit in that one of the coupling capacitors is replaced by a resistor. Its operating point is in one of the stable regions and when triggered by a small external pulse it generates a larger output pulse by moving to the other stable state and remaining there for a period determined by the circuit constants before reverting to its original state.

44. In the circuit at fig. 7 (*b*), the transistors are biased so that when power is applied, VT.1 will conduct and be driven into saturation whilst VT.2 will be cut off. The capacitor C1 couples the negative collector potential of VT.2 to the base of VT.1 and the capacitor is charged through the resistor R4 and the low saturation resistance of VT.1.

45. The application of a negative trigger pulse to the base of VT.2 through the capacitor C2 causes the transistor to conduct and subsequent regenerative action results in VT.1 being cut off and VT.2 saturated; the charged capacitor C1 holds the base of VT.1 at a positive potential almost equal to the supply voltage.

46. The capacitor C1 discharges through R3 and the low saturation resistance of VT.2 thus removing the reverse bias from the base of VT.1. When the base of VT.1 becomes forward biased, the transistor conducts and regenerative action again takes place until VT.1 is saturated and VT.2 is cut off so that the circuit is returned to its original state where it remains until another trigger pulse initiates a repetition of the cycle. The square waveform output is taken from the collector of either transistor.

Bistable circuit

47. The bistable circuit has its operating point in one of the two stable regions and when triggered to the other stable region through the application of a pulse it remains in that region until another pulse returns the circuit to its original state. The resistance and bias values are designed to drive the ON transistor into saturation.

48 Assuming that VT.1 in fig. 7 (*c*) is ON, its collector voltage will be very low and almost the whole of the supply voltage will be across the load resistor R1. The voltage of the bias battery Vb is divided by the resistors R6 and R2, the larger voltage being developed across R2 from which a positive potential is taken to reverse bias the base-emitter junction of VT.2 and drive the transistor into the OFF condition.

49. The output impedance of the cut off transistor VT.2 is very high and its collector voltage is almost equal to that of the supply, very little being dropped across the load resistor R4. This collector voltage is divided by the resistors R5 and R3 and a negative potential from the junction of the two resistors is applied to the base of VT.1 to increase the forward bias of its emitter-base junction and so drive the transistor into the saturated condition.

50. The conducting state of the circuit may be changed by a pulse of sufficient amplitude and appropriate polarity applied to the base or collector of either transistor, e.g. a negative pulse applied to the base of the OFF transistor, or to the collector of the ON transistor, will drive the OFF transistor into conduction. Alternatively, a positive pulse applied to the base of the ON transistor, or to the collector of the OFF transistor, will drive the ON transistor into the transition region.

Blocking oscillators

51. There are two types of blocking oscillator, free-running and triggered; the transistor in the former type is forward biased so that the circuit operates when d.c. power is applied. The transistor of the triggered type of blocking oscillator is reverse biased and its transistor is cut off in the quiescent state; application of a negative trigger pulse to the base of the transistor causes the circuit (*fig*. 8) to function as follows.

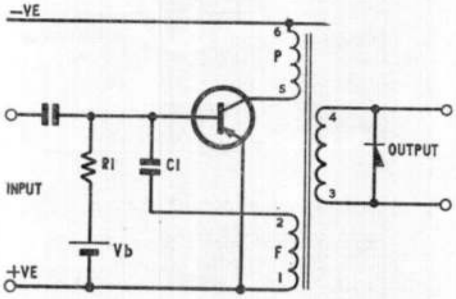


Fig. 8 Basic blocking oscillator circuit

52. As the collector current rises due to the forward bias applied to the base, the collector voltage becomes more positive and a voltage of opposite polarity induced in the feedback winding (F) of the transformer is coupled to the base to increase the forward bias. The transistor is driven quickly into saturation and the collector current becomes constant with the result that there is no voltage induced in the feedback winding.

53. The removal of the base drive due to the feedback voltage results in the transistor again becoming reverse biased and cut off. The collapse of the field due to the cessation of collector current induces a voltage in the winding which drives the transistor base positive and so assists the cut off action.

54. The free running oscillator circuit remains in the cut off state until the discharge of the capacitor (C1) causes the transistor to become forward biased and the cycle is then repeated. The triggered oscillator circuit remains in the cut off state until another triggering pulse initiates a further cycle of operations.

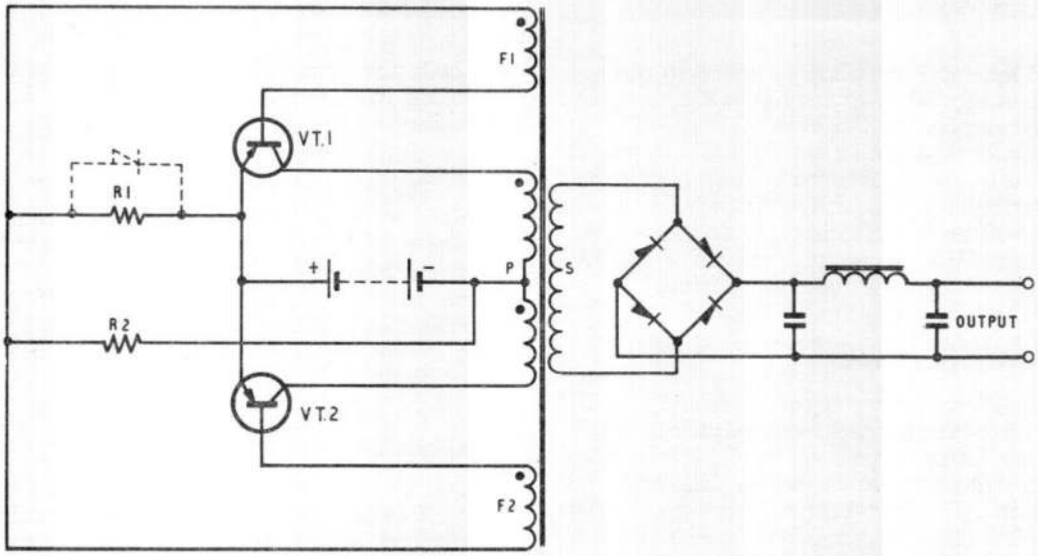
Static inverters and converters

55. Switching transistors operating from cut off to saturation are used in conjunction with transformers to generate square wave outputs which are transformed and rectified to provide various a.c. and d.c. power supplies from low d.c. voltage inputs. The basic circuits of static inverters and converters are similar but the latter have filter and rectifier circuits connected to the output transformers.

56. Fig. 9 shows a circuit diagram of a square wave generator having two switching transistors, in the common emitter arrangement, connected in push-pull to the centre-tapped primary winding of a saturable core transformer which also carries two feedback and an output winding. The hysteresis curve for the transformer core is illustrated at fig. 9 (*b*), and the output waveform at fig. 9 (*c*).

57. When d.c. is applied to the circuit one of the transistors conducts more than the other due to unbalance or to variations in component tolerances. Assuming that transistor VT.1 conducts the more heavily, the current through one half of the primary winding P will cause the flux in the transformer core to increase in density and it will move from point 1 towards the positive saturation region at point 2 in the curve at fig. 9 (*b*).

58. The increasing flux causes voltages to be induced in the two feedback windings F1 and F2 which drive the base of VT.1 more negative, thus increasing the conduction of that transistor, whilst the base of VT.2 is made more positive and the transistor is driven to the cut off state. When VT.1 becomes saturated the resistance of the collector-emitter



(*a*) *Diagram of static converter*

(*b*) *Hysteresis loop of saturable transformer*

(*c*) *Square wave output before and after rectification*

Fig. 9 Static converter diagram

circuit is very small and the full supply voltage is effectively across half of the transformer primary winding.

59. When the transformer core flux reaches saturation, shown at point 2 on the curve, its value becomes constant and the voltage across the primary winding falls, reducing the base driving current and consequently the collector current of VT.1. Regenerative action causes VT.1 to become cut off and the flux value falls, from point 2 to 3 on the curve, inducing voltages in the feedback windings which drive VT.2 into conduction and VT.1 further into the cut off region.

60. The increasing collector current of transistor VT.2 causes a greater flux density and its value moves from point 3 on the curve towards negative saturation at point 4. When this point is reached VT.1 and VT.2 are switched into conduction and cut off respectively in a manner similar to that described in the previous paragraph. The cycle of operations is then repeated at a frequency and output voltage determined by the transformer characteristics.

Starting circuits

61. Square wave oscillatory circuits do not start readily, especially under load conditions in low ambient temperatures. Various circuit modifications are made to facilitate oscillation, one of which is the use of resistors (R1 and R2 in fig. 9) which bias the transistors into conduction when d.c. power is applied.

Another method replaces R2 with a diode (shown dotted in fig. 9) which does not conduct initially, current flowing through the resistor R1 to the bases of both transistors causing the one with the higher amplification to start first. The base driving current for the conducting transistor is subsequently supplied through the low forward resistance of the diode.

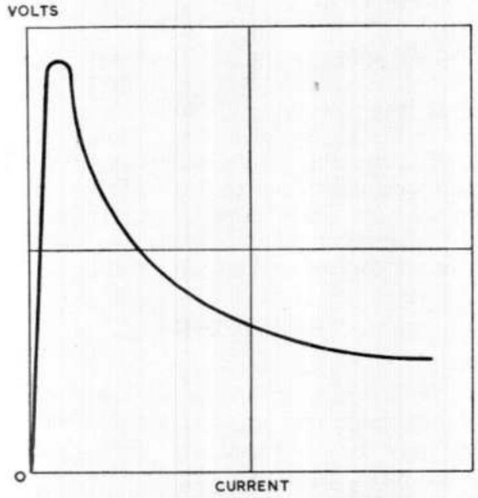


Fig. 10 Thermistor characteristics

Thermistors

62. Semiconductor Thermistors have a large negative temperature coefficient of resistance and have many applications in connection with stabilization, surge suppression and temperature measurement. Their resistance is linear for small values of current, as shown in fig. 10, but it becomes very non-linear under the heating effect of larger currents or increased ambient temperature. In some applications thermistors are used in conjunction with suitable resistors to obtain a combined resistance which is almost a linear function of temperature (*fig*. 11 *refers*). Small types of thermistor are directly heated by the circuit current passing through them; larger types have separate heater windings which are insulated electrically from the semiconductor.

63. Fig. 11 shows a transistor amplifier circuit in which a thermistor is used in conjunction with a resistor to minimize variations in emitter current due to temperature changes. The transistor is normally forward biased by a negative potential obtained from the centre of the voltage divider formed by the resistor R1 and the thermistor TH. A rise in temperature which causes more emitter current to flow will also lower the resistance of the thermistor so that more of the supply voltage is dropped across R1 and less across the thermistor. The base potential of the transistor is thus made less negative and the emitter current is reduced to approximately its normal value.

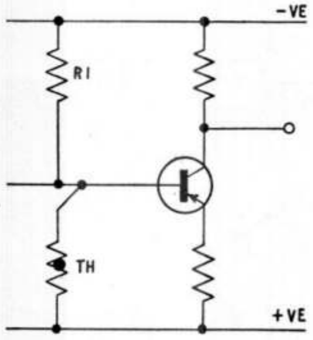
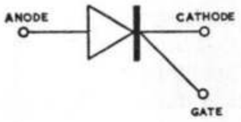


Fig. 11 Thermistor stabilized circuit

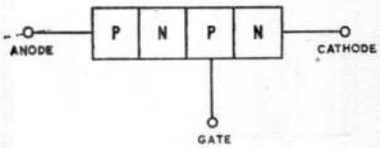
Silicon controlled rectifier

64. The silicon controlled rectifier is a semiconductor device having characteristics and applications similar in many respects to a gas-filled triode thermionic valve. It has two stable states and in the off condition it will block both forward and reverse currents, its reverse characteristics being similar to those of a normal reverse-biased silicon rectifier. Rapid switching to the on state can be effected by the application of a small pulse of current through a control electrode or 'gate'; the resultant forward current being limited only by the resistance of the external circuit. The applied voltage must be removed so as to reduce the current to a low value in order to return the device to the off condition.

65. The silicon controlled rectifier comprises four layers of semiconductor material in either a p–n–p–n or a n–p–n–p arrangement and having three electrodes, anode, cathode, and control or gate. Its construction may be regarded as a combination of a p–n–p and a n–p–n transistor, the outer p and n regions having the anode and cathode terminals attached to them whilst the central n and p regions, to one of which the control electrode is attached, are common to each 'transistor' and act as base regions.



(a) Graphical symbol



(b) Construction

Fig. 12 Silicon controlled rectifier

66. In the off condition with the device connected to a power supply, the junction between the two bases is reverse biased whilst both the junctions between the bases and the outer regions are forward biased. The current flow is very small and is due to the leakage current through the two 'transistors'.

67. The device is switched to the on state either by increasing the applied voltage to a value known as the breakover voltage, or by the application of a pulse of current through the control electrode. In this state both the base regions are saturated with carriers and the junction between them is forward biased and in consequence the voltage drop across the device is very low. Beyond the breakover point the current increases rapidly, its value being limited only by the connected load. If however the current should fall for any reason below a value termed the holding current, the device will revert to the off or forward blocking condition.

68. The following details apply to the Type C35A silicon controlled rectifier which is illustrated at item 6 in fig. 1:—

Forward current ..	16A (mean)
Forward voltage drop at max. output current	0·86V (full cycle mean)
Peak, one cycle, surge current	150A
Peak gate power ..	5W (mean=0·5W)
Operating temperature	—65°C to +125°C
Minimum breakover voltage	100V
Typical holding current	10mA
Typical gate current..	10mA at +1·5V (to fire)
Peak inverse voltage..	100V

69. Silicon controlled rectifiers may be used in similar applications to those of thyratrons, magnetic amplifiers and power transistors and also as inverters and converters, switches, relays, contactors and circuit breakers.

SERVICING

General

70. Semiconductor devices are fairly robust in construction and reliable in operation but they may be damaged by high ambient temperatures, excessive voltages or by d.c. supply voltages of the wrong polarity. They may also be damaged by the application of excessive heat during soldering operations. The following paragraphs contain details of precautions to be taken to avoid damage to components during servicing operations on equipment containing semiconductors. Information on the use of servicing equipment provisioned specifically for use with semiconductor devices will be published in this chapter as soon as the necessary details become available.

Power supplies

71. Before a direct current supply is connected to equipment containing semicon--ductors, a check should be made to ensure that both the voltage and its polarity are suitable for the equipment concerned.

Note . . .
The application of a power supply of the wrong polarity to transistors will result in their destruction.

72. In no circumstances should the maximum ratings of transistors be exceeded and precautions should be taken to prevent the application of d.c. voltages or transients from external sources, e.g. test equipment which may contain charged capacitors. It is advisable to connect the earth lead of such equipment first and then to touch the input lead on the earth point, to ensure that any capacitors are discharged, before connecting it into the circuit.

Use of testmeters and multimeters

73. The marked polarity of testmeter and multimeter terminals is normally related to the correct flow of current through the instrument movement and, when a resistance range is selected, the positive side of a dry battery is connected to the common negative terminal. Such instruments should not therefore be used for continuity tests or resistance measurements on transistorized circuits where there is any possibility of damage being caused by the testmeter battery.

Removal and replacement of components

74. Power supplies to transistorized equipment should always be switched off prior to any soldering operations or the disconnection of circuit components and plugs and sockets. Failure to observe this precaution may result in damage to the transistors.

Soldering

75. Soldering operations should be completed as quickly as practicable to prevent damage to semiconductors and associated miniaturized components due to the transfer of heat. Small, low voltage, soldering irons, preferably thermostatically controlled, should be used either without an earthing lead or alternatively with a lead providing a means of connecting the metalwork of the soldering iron to the earth point on the equipment being serviced. Mains voltage soldering irons should not be used.

Note . . .
Soldering irons used on transistorized equipment should not have their earth leads connected to earth terminals associated with mains supplies. This is because of the possibility of damage to the transistors due to induced voltages or to potential differences between the mains earthing terminal and the earthing point on the equipment.

Use of heat shunts

76. It is essential that a good heat shunt, such as a pair of smooth jawed pliers, is used when soldered joints are being made or undone on the terminal wires of semiconductor devices. The shunt should be used to hold the wire between the device and the point to be soldered and should be held in position until the joint has cooled. With an efficient heat shunt, that has been cooled before use, and a temperature controlled soldering iron, or one that has not been allowed to become overheated, an efficient soldered joint can be made without reaching the maximum permissible junction temperature of diodes and transistors. There is however a very small difference between the latter temperature and the heat transferred to the device even under optimum conditions; it is therefore necessary to complete soldering operations as quickly as practicable to avoid the transfer of heat which may impair the efficiency of the device or cause its complete destruction.

Terminal wires

77. Wherever it is practicable, the terminal wires of semiconductor devices should be left at their original length protected where necessary by insulating sleeves. When it is necessary to cut the protruding leads of transistors, a shearing tool should be used to sever the wire whilst the transistor side of the lead is held in a pair of flat-nosed pliers. This procedure reduces the possibility of damage to the very thin base wafer by shock loading consequent upon the use of unsuitable cutting tools.

78. Terminal wires should not be bent close to the device because of possible damage to glass to metal seals or the shearing of the wires. They should not be wrapped more than one turn around soldering tags and wherever it is practicable each tag should have only one wire soldered to it.

Mica washers

79. The collector on some types of power transistor is in electrical contact with a mounting screw which, together with a securing nut, is used to clamp the transistor to a heat sink formed by a relatively large area of heavy gauge aluminium. This arrangement keeps the junction temperature within permissible limits with high power outputs. When such transistors are operated under lower power conditions and it is necessary to insulate the collector from the chassis, a mica washer is fitted between the transistor and the chassis. Whenever these washers are being fitted, any sharp edges or protrusions on the transistor or chassis, which might puncture the washer, should be removed.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