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U-08B03
NOV 99

STUDENT HANDOUT

SPECIAL DEVICES

Terminal Learning Objective: Given a schematic, a faulty generator set electrical system, and applicable tools and test equipment, with the aid of references, repair the generator set electrical system so that it functions properly in accordance with the appropriate equipment technical manual. (1142.1.2)

Enabling Learning Objectives:

1. Given a list of schematic symbols, identify the schematic symbol for a zener diode, in accordance with FM 11-62. (1142.01.03at)

2. Given a list of diode characteristics, select the characteristics that apply to a zener diode, in accordance with FM 11-62. (1142.01.03au)

3. Given a list of operating characteristics, select the characteristics that apply to a silicon controlled rectifier, in accordance with FM 11-62. (1142.01.03ar)

4. Given list of operating characteristics, select the characteristics that apply to a unijunction transistor, in accordance with FM 11-62. (1142.01.03as)

BODY:

1. Zener Diode:

a. When a PN-junction is reversed biased, the majority carriers (holes in P material and electrons in N material) move away from the junction. The barrier or depletion region becomes wider, as our slide shows, and majority carrier current flow becomes very difficult across the high resistance of the wide depletion region. The presence of minority carriers causes a very small leakage current that remains nearly constant for all reverse voltages up to a certain value. Once this value has been exceeded, there is a sudden increase in the reverse current. The increase in current is called the "Breakdown Voltage". At breakdown, the reverse current increases very rapidly with a slight increase in the reverse voltage. Any diode can be reverse biased to the point of breakdown, but not every diode can safely dissipate the power associated with breakdown. A zener diode is a PN junction designed to operate in the reverse bias breakdown region.

b. This slide shows a graph of what we have just covered. Notice that when forward biased, the zener diode reacts like a normal diode, but when reverse biased, the reverse-bias voltage can be increased with extremely little current flow, (which is due to minority carriers), until we reach a point where suddenly there is a very large current flow and voltage does not increase further. This breakover voltage point is also known as the "Zener Knee". The zener knee is the most important point on the curve and will be explained further. The reason reverse voltage does not rise after breakdown but current does is as follows:

(1) At breakdown, the depletion region is as wide as it can possibly get, so its width becomes fixed at this point.

(2) Current will be allowed to flow because the voltage, (electrical pressure), is strong enough to overcome the resistance of the depletion region and force current carriers to move across the junction.

(3) Any further increase in reverse voltage will result in only a slight increase in voltage across the PN junction.

(4) Current can increase to a level considered damaging to the zener because after breakdown, the zener conducts like a short circuit with a strange phenomenon of a voltage drop being present due to the resistance of the depletion region.

(5) For this reason zener diodes are said to maintain a constant voltage after breakdown.

c. Zener diodes are almost always operated with a resistor in series with it to limit current flow to a safe value. This series resistor is known as a "Current limiting resistor".

d. Zener diodes can have breakdown voltages ranging from 2 to 200 volts. This is controlled during the manufacturing process by varying the level of doping, which results in varying the thickness of the depletion region.

e. Some of the symbols used to represent zener diodes are shown here. Note that the polarity markings are indicating that electron flow is with the arrow symbol instead of against it as in a normal PN junction diode. This is because breakdown diodes are operated in the reverse bias mode which means the current flow is by minority current carriers.

f. Zener diodes are used for many purposes, but their most widespread use is as voltage regulators. Once the breakdown voltage is reached, the voltage across the diode remains almost constant regardless of the supply voltage. Therefore, any load in parallel with it will have constant voltage applied to it.

2. Silicon Controlled Rectifiers (SCR'S):

a. Our next special device is the silicon controlled rectifier, or SCR. It is a member of a family of devices known as "Thyristors". The SCR is shown here both in a physical representation and schematically. Although it is not the same as a diode or transistor, it combines features of both, plus some of its own. Circuits using transistors or diodes may be greatly improved in some instances through the use of SCRs.

(1) The basic purpose of the SCR is to function as a switch that can turn on or off large amounts of power. It performs this function with no moving parts that wear out and no points that require replacing. There can be a tremendous power gain in the SCR; in some units a very small triggering current is able to switch several hundred amperes without exceeding its rated abilities. The SCR can often replace much slower and larger mechanical switches. It even has many advantages over its more complex and larger electronic-tube equivalent, the thyratron.

(2) The SCR is an extremely fast switch. It is difficult to cycle a mechanical switch several hundred times a minute; yet some SCRs can be switched 25,000 times a second. It takes just microseconds (millionths of a second) to turn them on or off. Varying the time that a switch is on as compared to the time that it is off regulates the amount of power flowing through the switch. Since most devices can operate on pulses of power (alternating current is a special form of alternating positive and negative pulses), the SCR can be used readily in control applications. Motor-speed controllers, inverters, remote switching units, controlled rectifiers, circuit overload protectors, latching relays, and computer logic circuits all use the SCR.

b. The SCR is made up of 4 layers of semiconductor material arranged PNPN. The construction is shown in view (A) of this slide. In function, the SCR has much in common with a diode, with a large positive potential on the anode and a large negative potential on the cathode, but the theory of operation of the SCR is best explained in terms of transistors.

(1) Consider the SCR as a transistor pair, one PNP and the other NPN, connected as shown in views (B) and (C). The anode is attached to the upper P-layer; the cathode, C, is part of the lower N-layer; and the gate terminal, G, goes to the P-layer of the NPN transistor. When a small positive potential is applied to the gate, Q2 is biased into conduction.

(2) This causes its collector current to rise and place electrons on the base of Q1 causing it to turn on. We now have current flow into the cathode and out the anode.

(3) Once turned on, we can remove, the positive potential from the gate, or leave it there, and the SCR will remain on because the collector of Q1 will continue to pull electrons from the base of Q2, causing it to feel a constant positive potential. The SCR will remain

on until current flow is stopped by breaking the circuit, or by reverse biasing it.

(4) The characteristic curve for the SCR is shown here. With no potential applied to the gate, the leakage current remains very small as the forward voltage from cathode to anode is increased until the breakdown point is reached. Here the center junction breaks down and the SCR begins to conduct heavily, and the voltage across the SCR becomes very low.

(5) The effect of a gate signal on the firing of an SCR is shown here. Breakdown of the center junction can be achieved at speeds approaching a microsecond by applying an appropriate signal to the gate lead, while holding the anode voltage constant. After breakdown, the voltage across the device is so low that the current flow through it from cathode to anode is essentially determined by the load it is feeding.

(6) The important thing to remember is that a small current from the gate can fire or trigger the SCR, changing it from practically an open circuit to a short circuit. The only way to change it back again is to reduce the current to a value less than the minimum forward-bias current. Gate current is required only until the anode current has completely built up to a point sufficient to sustain conduction (about 5 microseconds in resistive load circuits). After conduction from cathode to anode begins, removing the gate current has no effect.

c. The applications of the SCR as a rectifier are many. In fact, its many applications as a rectifier give this semiconductor device its name. When AC is applied to a rectifier, only the positive or negative halves of the sine waves flow through. All of each positive or negative half cycle appears in the output. When an SCR is used, the controlled rectifier may be turned on at any time during the half cycle, thus controlling the amount of DC power available from zero to maximum, as shown here. Since the output is actually DC pulses, suitable filtering can be added if continuous DC is needed. Thus any DC operated device can have controlled amounts of power applied to it. Notice that the SCR must be turned on at the desired time for each cycle. When an AC power source is used, the SCR is turned off automatically, since current and voltage drop to zero every half cycle. By using one SCR on positive alternations and one on negative, full-wave rectification can be accomplished, and control is obtained over the entire sine wave. The SCR serves in this application just as its name implies - as a controlled rectifier of AC voltage.

3. Unijuction Transistor (UJT):

a. The UJT is the first of our special devices. The UJT is a member of the thyristor family. It was originally called a double-based diode. Like the transistors we have already covered, it has three terminals, however, it has several advantages over conventional transistors. It is very stable over a wide range of temperatures and allows a reduction of components when used in the place of conventional transistors. A comparison is shown here. View A is a circuit using conventional transistors and view B is the same circuit using the UJT. As you can see, the UJT circuit has fewer components. Reducing the number of components reduces the cost, size and probability of failure.

(1) The physical appearance of the UJT is identical to that of the common transistor. As shown here, both have three leads and the same basic shape; the tab on the case indicates the emitter on both devices. The UJT, however, has a second base instead of a collector.

(2) As shown here, the lead differences are even more pronounced. Unlike the transistor, the UJT has only one PN junction. The area between base 1 and base 2 acts as a resistor when the UJT is properly biased.

(3) A conventional transistor needs a certain bias level between the emitter, base, and collector for proper conduction. The same principle is true for the UJT: it needs a certain bias level between the emitter and base 1 and also between base 1 and 2 for proper conduction.

(4) The normal bias arrangement for the UJT is shown here. A positive 10 volts is placed on base 2 and a ground on base 1. The area between base 1 and base 2 then acts as a resistor. If a reading were taken between base 1 and base 2, the meter would indicate the full 10 volts as shown. Theoretically, if one meter lead were connected to base 1 and the other lead to some point between base 1 and base 2, the meter could read some voltage less than 10 volts. This concept is illustrated here. The sequential rise in voltage is called a voltage gradient.

(5) The emitter of the UJT can be viewed as the wiper arm of a variable resistor. If the voltage level on the emitter is more positive than the voltage gradient level at the emitter-base material contact point, then the UJT is forward biased. The UJT will conduct heavily (almost a short circuit) from base 1 to the emitter. The emitter is fixed in position by the manufacturer. The level of the voltage gradient therefore depends upon the amount of bias voltage.

(a) If the voltage level on the emitter is less positive than the voltage gradient opposite the emitter, the UJT is then reverse biased. No current will flow from base 1 to the emitter. However, a small current, called reverse current, will flow from the emitter to base 2. The reverse current is caused by the impurities used in the construction of the UJT and is in the form of minority carriers.

(b) More than forty distinct types of UJT's are presently in use. One of the most common applications is in switching circuits. They are also used extensively in oscillators and wave shaping circuits.

Reference FM 11-62