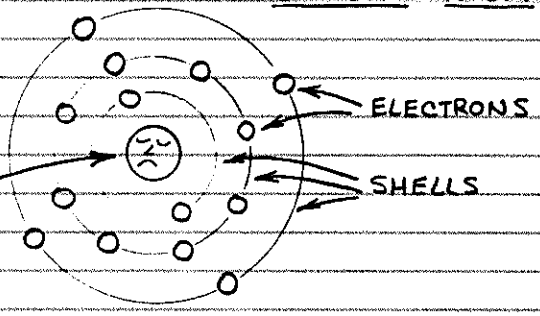
3. SEMICONDUCTORS

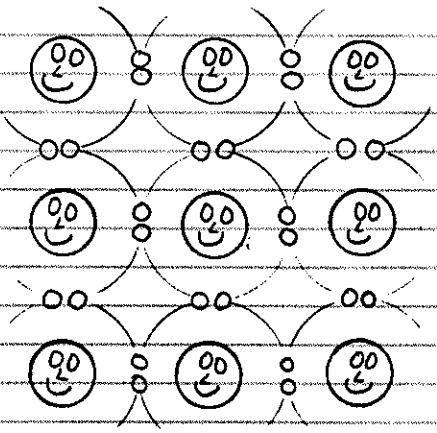
THE MOST EXCITING AND IMPORTANT ELECTRONIC COMPONENTS ARE MADE FROM CRYSTALS CALLED SEMICONDUCTORS. DEPENDING ON CERTAIN CONDITIONS, A SEMICONDUCTOR CAN ACT LIKE A CONDUCTOR OR AN INSULATOR.

SILICON

THERE ARE MANY DIFFERENT SEMICONDUCTING MATERIALS, BUT SILICON, THE MAIN INGREDIENT OF SAND, IS THE MOST POPULAR.

A SILICON ATOM HAS BUT FOUR ELECTRONS IN ITS OUTERMOST SHELL, BUT IT WOULD LIKE TO HAVE EIGHT. THEREFORE, A SILICON ATOM WILL LINK UP WITH FOUR OF ITS NEIGHBORS TO SHARE ELECTRONS:



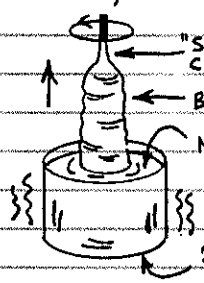


A CLUSTER OF SILICON ATOMS SHARING OUTER ELECTRONS FORMS A REGULAR ARRANGEMENT CALLED A CRYSTAL.

← THIS IS A MAGNIFIED VIEW OF A SILICON CRYSTAL. TO KEEP THINGS SIMPLE, ONLY THE OUTER ELECTRONS OF EACH ATOM ARE SHOWN.

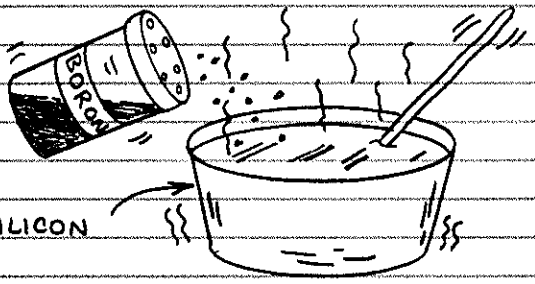
SILICON FORMS 27.7 % OF THE EARTH'S CRUST! ONLY OXYGEN IS MORE COMMON. IT'S NEVER FOUND IN THE PURE STATE. WHEN PURIFIED, IT'S DARK GRAY IN COLOR.

SILICON AND DIAMOND SHARE THE SAME CRYSTAL STRUCTURE AND OTHER PROPERTIES. BUT SILICON IS NOT TRANSPARENT.



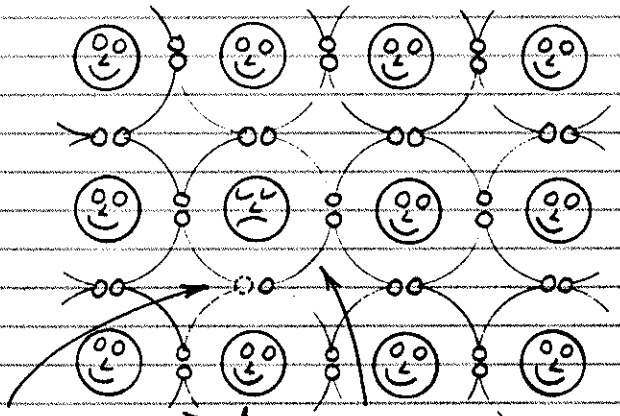
SILICON CAN BE GROWN INTO BIG CRYSTALS. IT'S CUT INTO WAFERS FOR MAKING ELECTRONIC PARTS.

☐ SILICON RECIPES — PURE SILICON ISN'T VERY USEFUL. THAT'S WHY SILICON MAKERS SPICE UP THEIR SILICON RECIPES WITH A DASH OF PHOSPHORUS, BORON OR OTHER GOODIES. THIS IS CALLED DOPING THE SILICON. WHEN GROWN INTO CRYSTALS, DOPED SILICON HAS VERY USEFUL ELECTRONIC PROPERTIES!

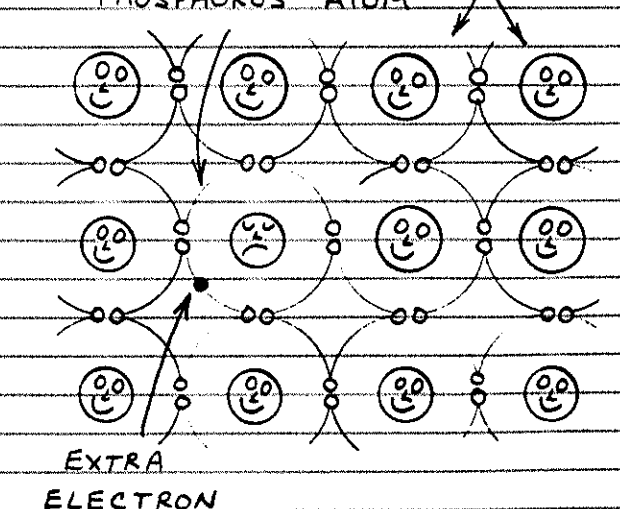


☐ P & N SPICED SILICON LOAF — BORON, PHOSPHORUS AND CERTAIN OTHER ATOMS CAN JOIN WITH SILICON ATOMS TO FORM CRYSTALS. HERE'S THE CATCH: A BORON ATOM HAS ONLY THREE ELECTRON IN ITS OUTER SHELL. AND A PHOSPHORUS ATOM HAS FIVE ELECTRONS IN ITS OUTER SHELL. SILICON WITH EXTRA PHOSPHORUS ELECTRONS IS CALLED N-TYPE SILICON (N = NEGATIVE). SILICON WITH ELECTRON DEFICIENT BORON ATOMS IS CALLED P-TYPE SILICON (P = POSITIVE).

☐ P-TYPE SILICON — A BORON ATOM IN A CLUSTER OF SILICON ATOMS LEAVES A VACANT ELECTRON OPENING CALLED A HOLE. IT'S POSSIBLE FOR AN ELECTRON FROM A NEARBY ATOM TO "FALL" INTO THE HOLE. THEREFORE, THE HOLE HAS MOVED TO A NEW LOCATION. REMEMBER, HOLES CAN MOVE THROUGH SILICON (JUST AS BUBBLES MOVE THROUGH WATER).



☐ N-TYPE SILICON — A PHOSPHORUS ATOM IN A CLUSTER OF SILICON ATOMS DONATES AN EXTRA ELECTRON. THIS EXTRA ELECTRON CAN MOVE THROUGH THE CRYSTAL WITH COMPARATIVE EASE. IN OTHER WORDS, N-TYPE SILICON CAN CARRY AN ELECTRICAL CURRENT. BUT SO CAN P-TYPE SILICON! HOLES "CARRY" THE CURRENT.



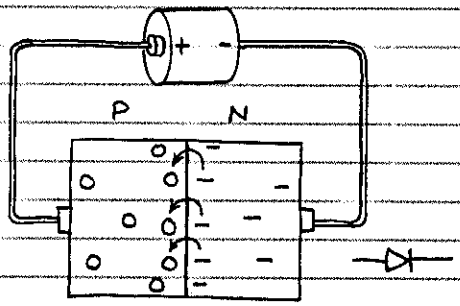
THE DIODE

BOTH P-TYPE AND N-TYPE SILICON CONDUCT ELECTRICITY. THE RESISTANCE OF BOTH TYPES IS DETERMINED BY THE PROPORTION OF HOLES OR SURPLUS ELECTRONS. THEREFORE BOTH TYPES CAN FUNCTION AS RESISTORS. AND THEY WILL CONDUCT ELECTRICITY IN ANY DIRECTION.

BY FORMING SOME P-TYPE SILICON IN A CHIP OF N-TYPE SILICON, ELECTRONS WILL FLOW THROUGH THE SILICON IN ONLY ONE DIRECTION. THIS IS THE PRINCIPLE OF THE DIODE. THE P-N INTERFACE IS CALLED THE PN JUNCTION.

☐ HOW THE DIODE WORKS — HERE'S A SIMPLIFIED EXPLANATION OF HOW A DIODE CONDUCTS ELECTRICITY IN ONE DIRECTION (FORWARD) WHILE BLOCKING THE FLOW OF CURRENT IN THE OPPOSITE DIRECTION (REVERSE).

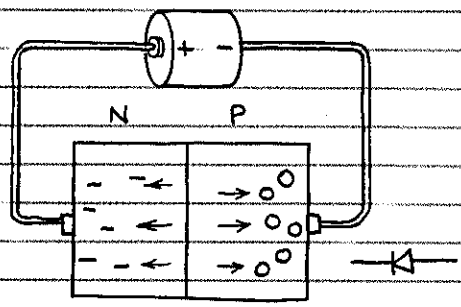
FORWARD BIAS



← ELECTRON FLOW
→ HOLE FLOW

HERE THE CHARGE FROM THE BATTERY REPELS HOLES AND ELECTRONS TOWARD THE JUNCTION. IF THE VOLTAGE EXCEEDS 0.6-VOLT (SILICON), THEN ELECTRONS WILL CROSS THE JUNCTION AND COMBINE WITH HOLES. A CURRENT THEN FLOWS.

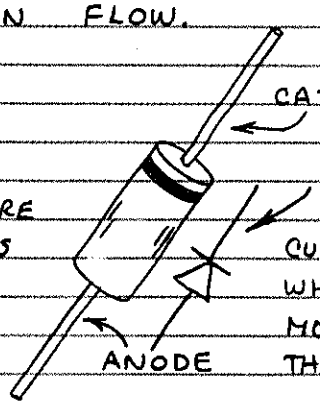
REVERSE BIAS



NO CURRENT FLOW

HERE THE CHARGE FROM THE BATTERY ATTRACTS HOLES AND ELECTRONS AWAY FROM THE JUNCTION. THEREFORE, NO CURRENT CAN FLOW.

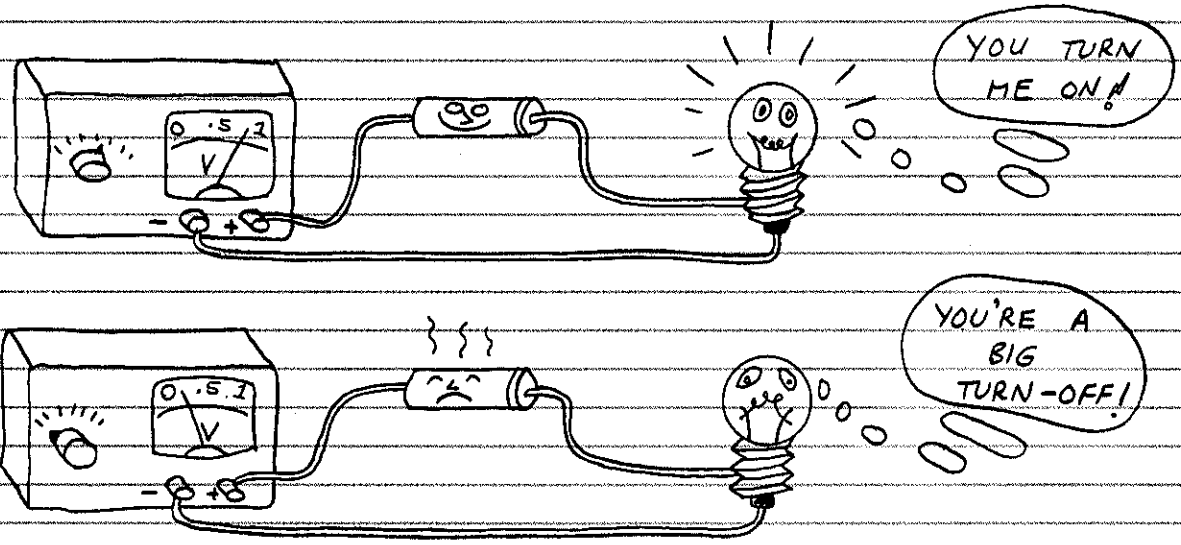
☐ A TYPICAL DIODE — DIODES ARE COMMONLY ENCLOSED IN SMALL GLASS CYLINDERS. A DARK BAND MARKS THE CATHODE TERMINAL. THE OPPOSITE TERMINAL IS THE ANODE



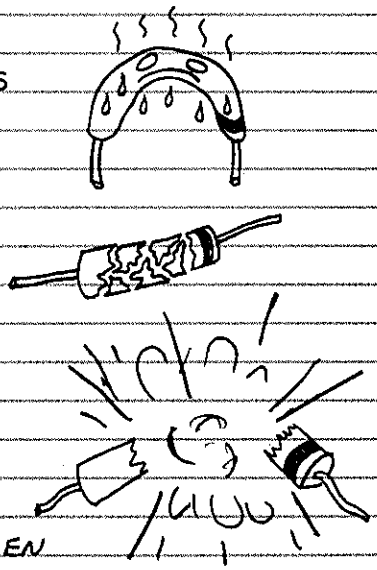
CURRENT FLOWS WHEN ANODE IS MORE POSITIVE THAN CATHODE.

☐ DIODE OPERATION — YOU ALREADY KNOW A DIODE IS LIKE AN ELECTRONIC ONE-WAY VALVE. IT'S IMPORTANT TO UNDERSTAND SOME ADDITIONAL ASPECTS OF DIODE OPERATION. HERE ARE SOME KEY ONES:

1. A DIODE WILL NOT CONDUCT UNTIL THE FORWARD VOLTAGE REACHES A CERTAIN THRESHOLD POINT. FOR SILICON DIODES THIS VOLTAGE IS ABOUT 0.6-VOLT.



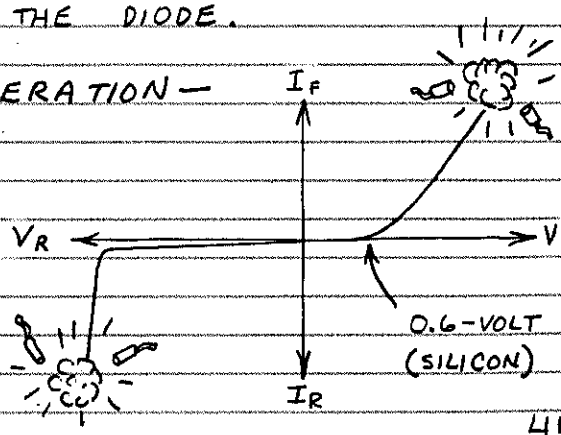
2. IF THE FORWARD CURRENT BECOMES EXCESSIVE, THE SEMICONDUCTOR CHIP MAY CRACK OR MELT! AND THE CONTACTS MAY SEPARATE. IF THE CHIP MELTS, THE DIODE MAY SUDDENLY CONDUCT IN BOTH DIRECTIONS. THE RESULTING HEAT MAY VAPORIZE THE CHIP!



3. TOO MUCH REVERSE VOLTAGE WILL CAUSE A DIODE TO CONDUCT IN THE WRONG DIRECTION. SINCE THIS VOLTAGE IS FAIRLY HIGH, THE SUDDEN CURRENT SURGE MAY ZAP THE DIODE.

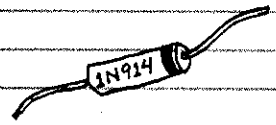
☐ SUMMING UP DIODE OPERATION — THIS GRAPH SUMS UP DIODE OPERATION. (IT'S APPROXIMATE.)

V_F = FORWARD VOLTAGE
V_R = REVERSE VOLTAGE
I_F = FORWARD CURRENT
I_R = REVERSE CURRENT



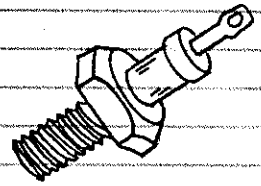
☐ TYPES OF DIODES — MANY DIFFERENT KINDS OF DIODES ARE AVAILABLE. HERE ARE SOME OF THE MAJOR TYPES:

SMALL SIGNAL.



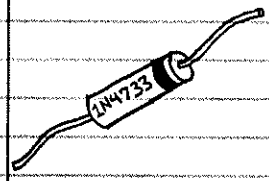
SMALL SIGNAL DIODES ARE USED TO TRANSFORM LOW CURRENT AC TO DC, DETECT (DEMODULATE) RADIO SIGNALS, MULTIPLY VOLTAGE, PERFORM LOGIC, ABSORB VOLTAGE SPIKES, ETC.

POWER RECTIFIER.



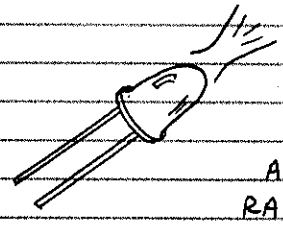
FUNCTIONALLY IDENTICAL TO SMALL SIGNAL DIODES, POWER RECTIFIERS CAN HANDLE MUCH MORE CURRENT. THEY ARE INSTALLED IN LARGE METAL PACKAGES THAT SOAK UP EXCESS HEAT AND TRANSFER IT TO A METAL HEAT SINK. USED MAINLY IN POWER SUPPLIES.

ZENER.



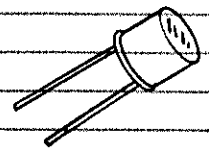
THE ZENER DIODE IS DESIGNED TO HAVE A SPECIFIC REVERSE BREAKDOWN (CONDUCTION) VOLTAGE. THIS MEANS ZENER DIODES CAN FUNCTION LIKE A VOLTAGE SENSITIVE SWITCH. ZENER DIODES HAVING BREAKDOWN VOLTAGES (V_Z) OF FROM ABOUT 2-VOLTS TO 200-VOLTS ARE AVAILABLE.

LIGHT-EMITTING.



ALL DIODES EMIT SOME ELECTROMAGNETIC RADIATION WHEN FORWARD BIASED. DIODES MADE FROM CERTAIN SEMICONDUCTORS (LIKE GALLIUM ARSENIDE PHOSPHIDE) EMIT CONSIDERABLY MORE RADIATION THAN SILICON DIODES. THEY'RE CALLED LIGHT-EMITTING DIODES (LEDs).

PHOTODIODE.

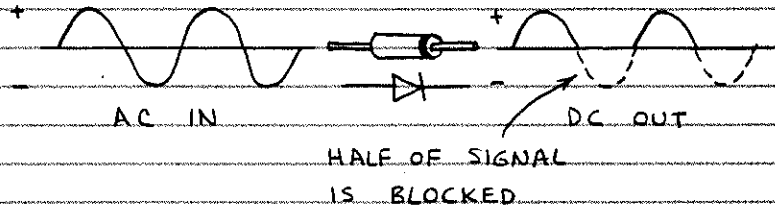


ALL DIODES RESPOND TO SOME DEGREE WHEN ILLUMINATED BY LIGHT. DIODES DESIGNED SPECIFICALLY TO DETECT LIGHT ARE CALLED PHOTODIODES. THEY INCLUDE A GLASS OR PLASTIC WINDOW THROUGH WHICH THE LIGHT ENTERS. OFTEN THEY HAVE A LARGE, EXPOSED JUNCTION REGION. SILICON MAKES GOOD PHOTODIODES.

HOW DIODES ARE USED

IN CHAPTER 9 YOU'LL SEE HOW VARIOUS TYPES OF DIODES ARE USED IN MANY APPLICATIONS. FOR NOW HERE ARE TWO OF THE MOST IMPORTANT ROLES FOR SMALL SIGNAL DIODES AND RECTIFIERS:

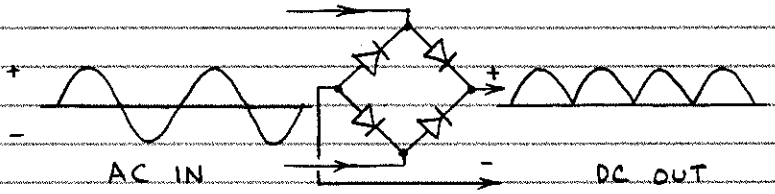
☐ HALF-WAVE RECTIFIER



AN UNDULATING (AC) SIGNAL (OR VOLTAGE) IS RECTIFIED INTO A SINGLE POLARITY (DC) SIGNAL (OR VOLTAGE).

☐ FULL-WAVE RECTIFIER

P. 101



THIS 4-DIODE "NETWORK" (OR BRIDGE RECTIFIER) RECTIFIES BOTH HALVES OF AN AC SIGNAL.

MORE ABOUT THE DIRECTION OF CURRENT FLOW

AN ELECTRICAL CURRENT IS THE MOVEMENT OF ELECTRONS THROUGH A CONDUCTOR OR SEMICONDUCTOR. SINCE ELECTRONS MOVE FROM A NEGATIVELY CHARGED TO A POSITIVELY CHARGED REGION, WHY DOES THE ARROWHEAD IN A DIODE SYMBOL POINT IN THE OPPOSITE DIRECTION? THERE ARE TWO REASONS:

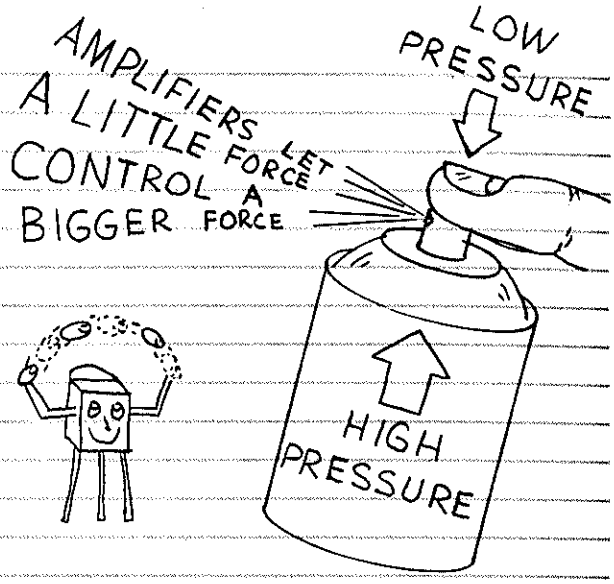
1. BEGINNING WITH BENJAMIN FRANKLIN, IT WAS TRADITIONALLY ASSUMED ELECTRICITY FLOWS FROM A POSITIVELY CHARGED TO A NEGATIVELY CHARGED REGION. THE DISCOVERY OF THE ELECTRON CORRECTED THAT. (BUT MOST ELECTRICAL CIRCUIT DIAGRAMS TODAY STILL FOLLOW THE OLD TRADITION IN WHICH THE POSITIVE POWER SUPPLY CONNECTION IS PLACED ABOVE THE NEGATIVE CONNECTION AS IF GRAVITY SOMEHOW INFLUENCES THE FLOW OF A CURRENT.)

2. IN A SEMICONDUCTOR, AS SHOWN ON PAGE 44, HOLES FLOW IN THE DIRECTION OPPOSITE THAT OF ELECTRON FLOW. IT'S THEREFORE COMMON TO REFER TO POSITIVE CURRENT FLOW IN SEMICONDUCTORS.

FOR ACCURACY, IN THIS BOOK "CURRENT FLOW" REFERS TO ELECTRON FLOW. BUT WE'RE STUCK WITH SYMBOLS THAT INDICATE HOLE FLOW.

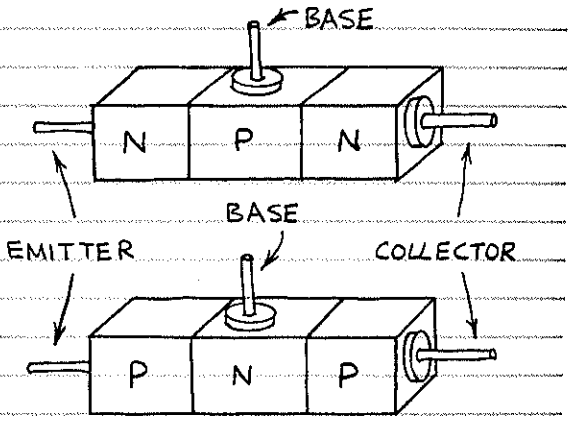
THE TRANSISTOR

TRANSISTORS ARE SEMICONDUCTOR DEVICES WITH THREE LEADS. A VERY SMALL CURRENT OR VOLTAGE AT ONE LEAD CAN CONTROL A MUCH LARGER CURRENT FLOWING THROUGH THE OTHER TWO LEADS. THIS MEANS TRANSISTORS CAN BE USED AS AMPLIFIERS AND SWITCHES. THERE ARE TWO MAIN FAMILIES OF TRANSISTORS: BIPOLAR AND FIELD-EFFECT.

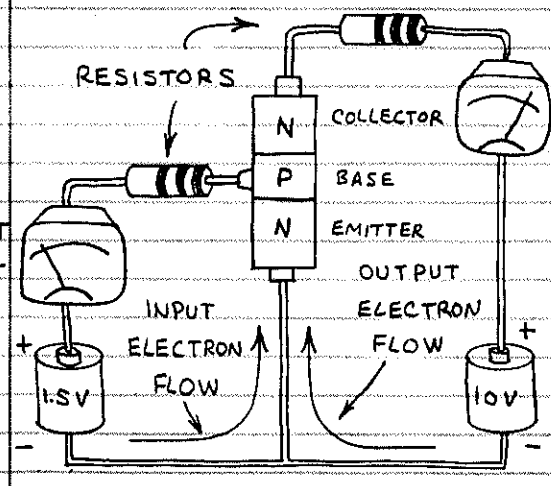


BIPOLAR TRANSISTORS

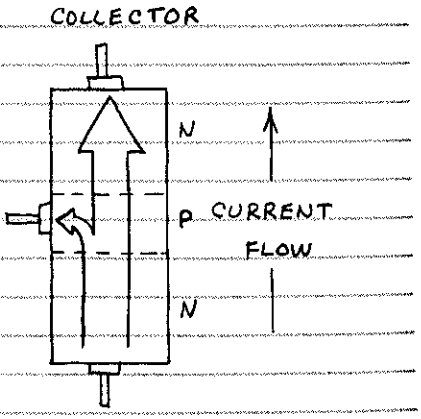
ADD A SECOND JUNCTION TO A PN JUNCTION DIODE AND YOU GET A 3-LAYER SILICON SANDWICH. THE SANDWICH CAN BE EITHER NPN OR PNP. EITHER WAY, THE MIDDLE LAYER ACTS LIKE A FAUCET OR GATE THAT CONTROLS THE CURRENT MOVING THROUGH THE THREE LAYERS.



☐ BIPOLAR TRANSISTOR OPERATION — THE THREE LAYERS OF A BIPOLAR TRANSISTOR ARE THE EMITTER, BASE AND COLLECTOR. THE BASE IS VERY THIN AND HAS FEWER DOPING ATOMS THAN THE EMITTER AND COLLECTOR. THEREFORE A VERY SMALL EMITTER-BASE CURRENT WILL CAUSE A MUCH LARGER EMITTER-COLLECTOR CURRENT TO FLOW.



THE RESISTORS PROTECT THE TRANSISTOR FROM TOO MUCH CURRENT (WHICH CAN CAUSE EXCESSIVE HEAT).

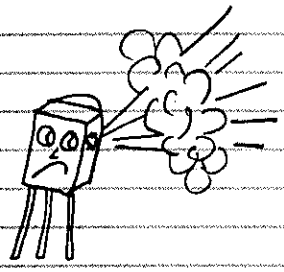


☐ MORE ABOUT BIPOLAR TRANSISTOR OPERATION — DIODES AND TRANSISTORS SHARE SEVERAL KEY FEATURES:

1. THE BASE-EMITTER JUNCTION (OR DIODE) WILL NOT CONDUCT UNTIL THE FORWARD VOLTAGE EXCEEDS 0.6-VOLT.

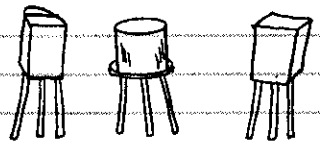
2. TOO MUCH CURRENT WILL CAUSE A TRANSISTOR TO BECOME HOT AND OPERATE IMPROPERLY. IF A TRANSISTOR IS HOT WHEN TOUCHED, DISCONNECT THE POWER TO IT!

3. TOO MUCH CURRENT OR VOLTAGE MAY DAMAGE OR PERMANENTLY DESTROY THE SEMICONDUCTOR CHIP THAT FORMS A TRANSISTOR. IF THE CHIP ISN'T HARMED, ITS TINY CONNECTION WIRES MAY MELT OR SEPARATE FROM THE CHIP. NEVER CONNECT A TRANSISTOR BACKWARDS!



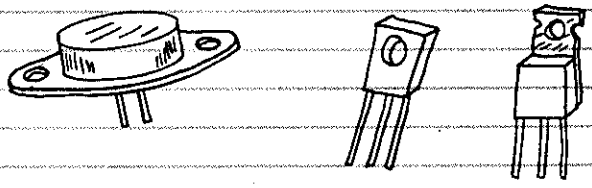
☐ KINDS OF TRANSISTORS — MANY DIFFERENT KINDS OF TRANSISTORS ARE AVAILABLE. HERE ARE EXAMPLES OF THE MOST IMPORTANT:

SMALL SIGNAL AND SWITCHING.



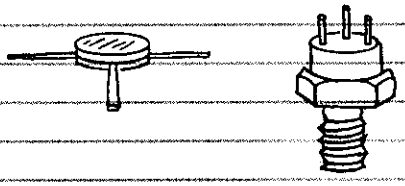
SMALL SIGNAL TRANSISTORS ARE USED TO AMPLIFY LOW LEVEL SIGNALS. SWITCHING TRANSISTORS ARE DESIGNED TO BE OPERATED FULLY ON OR OFF. SOME TRANSISTORS CAN BOTH AMPLIFY AND SWITCH EQUALLY WELL.

POWER.



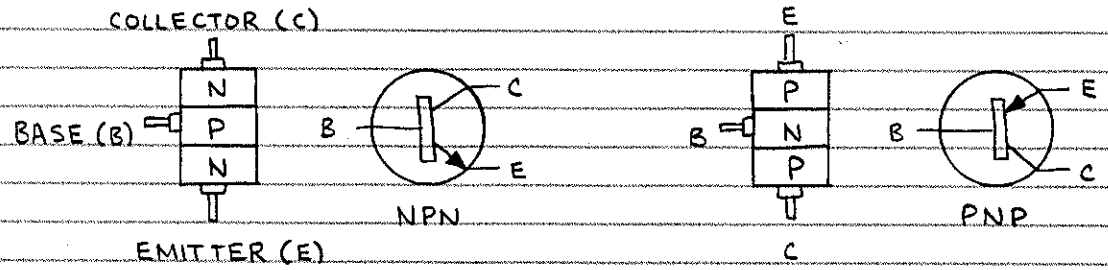
POWER TRANSISTORS ARE USED IN HIGH POWER AMPLIFIERS AND POWER SUPPLIES. LARGE SIZE AND EXPOSED METAL SURFACES KEEP THEM COOL.

HIGH-FREQUENCY.



HIGH-FREQUENCY TRANSISTORS OPERATE AT RADIO, TELEVISION AND MICROWAVE FREQUENCIES. THE BASE REGION IS VERY THIN AND THE ACTUAL CHIP IS VERY SMALL.

☐ BIPOLAR TRANSISTOR SYMBOLS — ARROWS POINT IN DIRECTION OF HOLE FLOW.



HOW BIPOLAR TRANSISTORS ARE USED

WHEN THE BASE OF AN NPN TRANSISTOR IS GROUNDED (0 VOLTS), NO CURRENT FLOWS FROM THE EMITTER TO THE COLLECTOR (THE TRANSISTOR IS "OFF"). IF THE BASE IS FORWARD-BIASED BY AT LEAST 0.6 VOLT, A CURRENT WILL FLOW FROM THE EMITTER TO THE COLLECTOR (THE TRANSISTOR IS "ON"). WHEN OPERATED IN ONLY THESE TWO MODES, THE TRANSISTOR FUNCTIONS AS A SWITCH. IF THE BASE IS FORWARD-BIASED, THE EMITTER-COLLECTOR CURRENT WILL FOLLOW VARIATIONS IN A MUCH SMALLER BASE CURRENT. THE TRANSISTOR THEN FUNCTIONS AS AN AMPLIFIER. THIS DISCUSSION APPLIES TO A TRANSISTOR IN WHICH THE EMITTER IS THE GROUND CONNECTION FOR BOTH THE INPUT AND OUTPUT AND IS CALLED THE COMMON-EMITTER CIRCUIT. SOME SIMPLIFIED COMMON-EMITTER CIRCUITS ARE SHOWN BELOW. SO YOU CAN SEE HOW THEY ARE USED IN REAL CIRCUITS, EACH EXAMPLE REFERS TO A TYPICAL WORKING APPLICATION IN CHAPTER 9.

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☐ A BIPOLAR TRANSISTOR SWITCH

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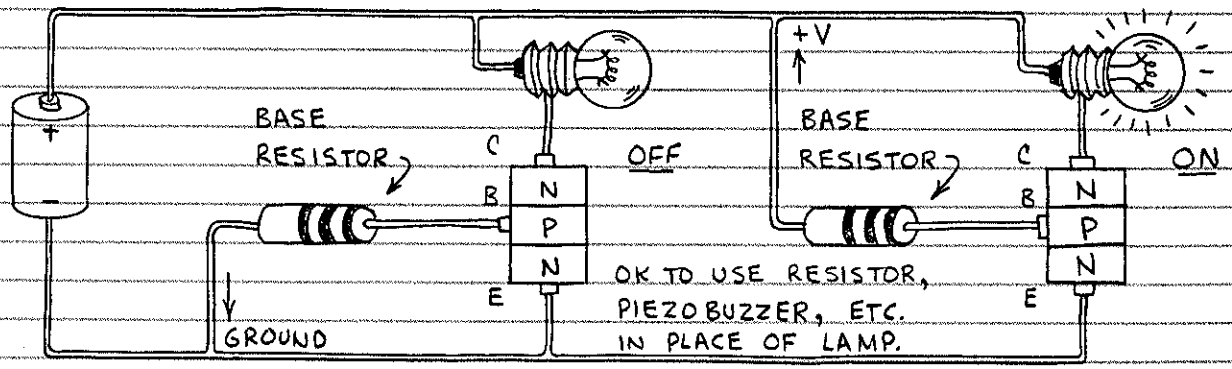
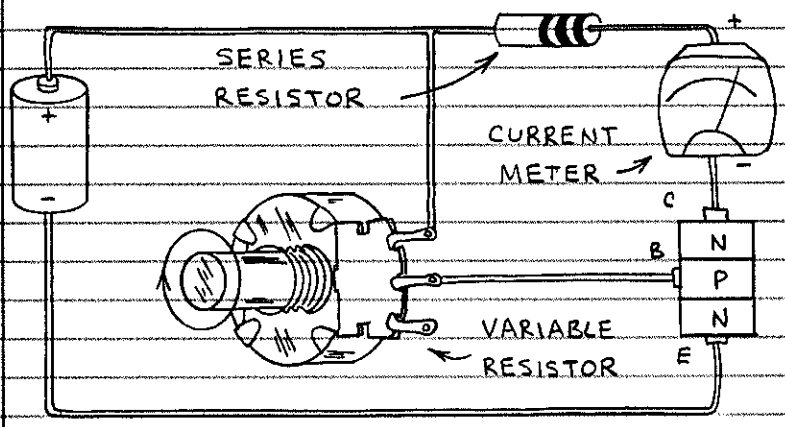


ONLY TWO INPUTS ARE POSSIBLE: GROUND (0 VOLTS) AND THE POSITIVE BATTERY VOLTAGE (+V). THEREFORE THE TRANSISTOR IS OFF OR ON. A TYPICAL BASE RESISTANCE IS 5,000 TO 10,000 OHMS. (IF THE RESISTOR IS REPLACED BY A WIRE, THE LAMP CAN BE SWITCHED ON OR OFF FROM A CONSIDERABLE DISTANCE.)

☐ A BIPOLAR TRANSISTOR DC AMPLIFIER — THE VARIABLE RESISTOR FORWARD BIASES THE TRANSISTOR AND CONTROLS THE INPUT (BASE-EMITTER) CURRENT. THE METER INDICATES THE OUTPUT (COLLECTOR-EMITTER) CURRENT. THE SERIES RESISTOR PROTECTS THE METER FROM EXCESSIVE CURRENT.



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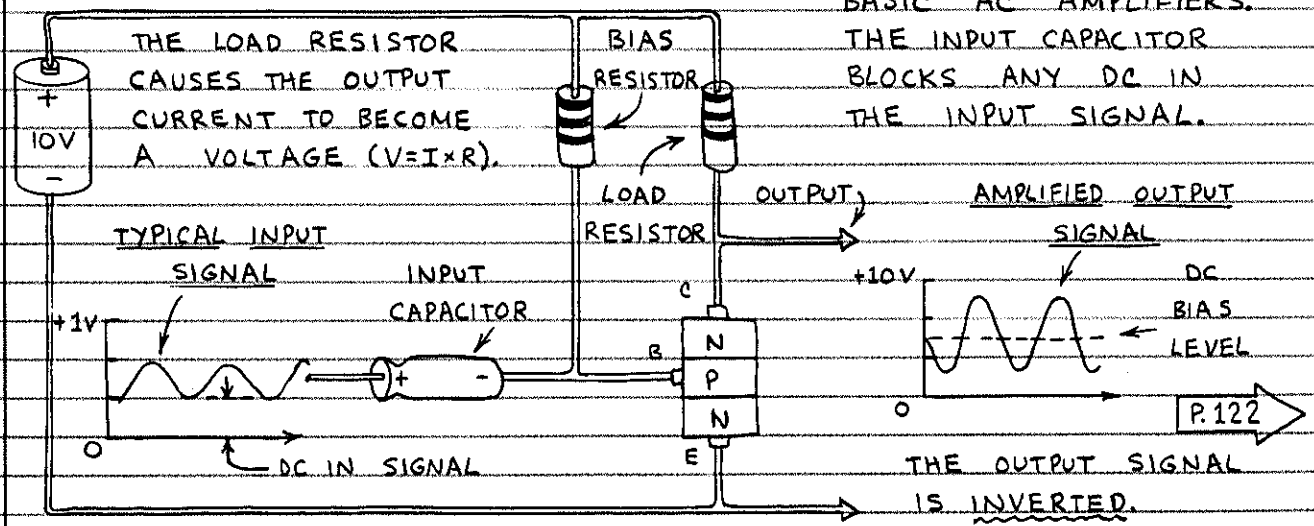
IN A WORKING CIRCUIT, THE VARIABLE RESISTOR MAY BE IN SERIES WITH A SECOND COMPONENT HAVING A RESISTANCE THAT VARIES WITH TEMPERATURE, LIGHT, MOISTURE, ETC. (WATER IS THE VARIABLE RESISTANCE IN THE MOISTURE METER ON P. 104.) WHEN THE INPUT SIGNAL CHANGES RAPIDLY, AN AC AMPLIFIER SUCH AS THE ONE BELOW IS USED.

☐ A BIPOLAR TRANSISTOR AC AMPLIFIER — THIS IS THE SIMPLEST OF SEVERAL BASIC AC AMPLIFIERS. THE INPUT CAPACITOR BLOCKS ANY DC IN THE INPUT SIGNAL.



P. 122

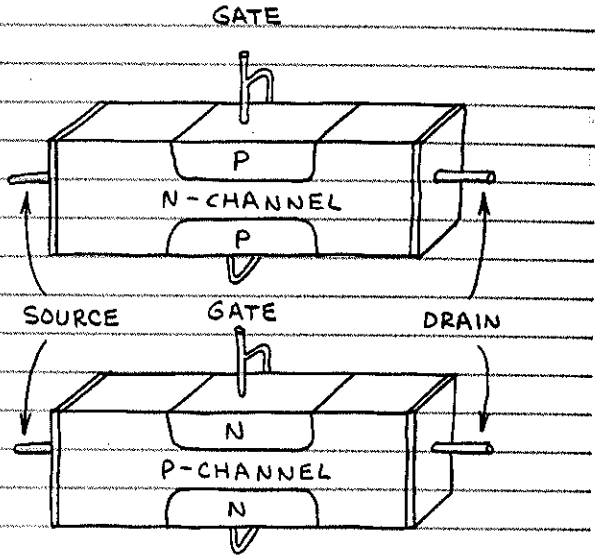
THE BIAS RESISTOR IS SELECTED TO GIVE AN OUTPUT VOLTAGE OF ABOUT HALF THE BATTERY VOLTAGE. THE AMPLIFIED SIGNAL "RIDES" ON THIS STEADY OUTPUT VOLTAGE AND VARIES ABOVE AND BELOW IT. (WITHOUT THE BIAS RESISTOR, ONLY THE POSITIVE HALF OF THE INPUT SIGNAL ABOVE 0.6 VOLT (SEE P. 45) WILL BE AMPLIFIED. THIS WILL CAUSE SEVERE DISTORTION.) TO SEE ONE WAY A WORKING VERSION OF THIS AMPLIFIER IS USED, TURN NOW TO P. 122 AND LOOK AT THE OUTPUT SECTION OF THE LIGHTWAVE TRANSMITTER.

FIELD-EFFECT TRANSISTORS

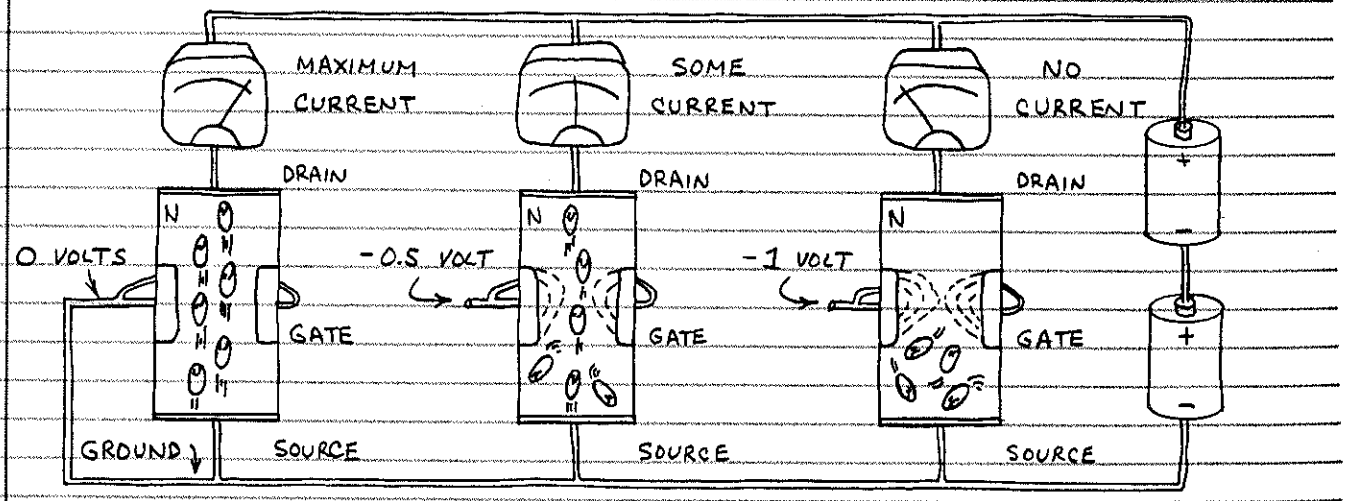
FIELD-EFFECT TRANSISTORS (OR FETs) HAVE BECOME MORE IMPORTANT THAN BIPOLAR TRANSISTORS. THEY ARE EASY TO MAKE AND REQUIRE LESS SILICON. THERE ARE TWO MAJOR FET FAMILIES, JUNCTION AND METAL-OXIDE-SEMICONDUCTOR. IN BOTH KINDS AN OUTPUT CURRENT IS CONTROLLED BY A SMALL INPUT VOLTAGE AND PRACTICALLY NO INPUT CURRENT!

JUNCTION FETs

THE TWO MAIN KINDS OF FETs ARE N-CHANNEL AND P-CHANNEL. THE CHANNEL IS LIKE A SILICON RESISTOR THAT CONDUCTS CURRENT MOVING FROM THE SOURCE TO THE DRAIN. A VOLTAGE AT THE GATE INCREASES THE CHANNEL RESISTANCE AND REDUCES THE DRAIN-SOURCE CURRENT. THEREFORE THE FET CAN BE USED AS AN AMPLIFIER OR A SWITCH.



☐ JUNCTION FET OPERATION — THE ARRANGEMENT BELOW SHOWS HOW AN N-CHANNEL FET WORKS. A NEGATIVE GATE VOLTAGE CREATES TWO HIGH RESISTANCE REGIONS (THE FIELD) IN THE CHANNEL ADJACENT TO THE P-TYPE SILICON. MORE GATE VOLTAGE WILL CAUSE THE FIELDS TO MERGE TOGETHER AND COMPLETELY BLOCK THE CURRENT. THE GATE-CHANNEL RESISTANCE IS VERY HIGH.



☐ MORE ABOUT JUNCTION FETs — SINCE THEY ARE VOLTAGE CONTROLLED, JUNCTION FETs (OR JFETs) HAVE IMPORTANT ADVANTAGES OVER CURRENT-CONTROLLED BIPOLAR TRANSISTORS:

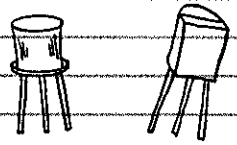
1. THE GATE-CHANNEL RESISTANCE OF A JFET IS VERY HIGH (MILLIONS OF OHMS). THEREFORE THE JFET HAS LITTLE OR NO EFFECT ON EXTERNAL COMPONENTS OR CIRCUITS CONNECTED TO ITS GATE.

2. THE VERY HIGH GATE-CHANNEL RESISTANCE MEANS PRACTICALLY NO CURRENT FLOWS IN THE GATE CIRCUIT. (WHY IS THE RESISTANCE SO HIGH? THE GATE AND CHANNEL FORM A DIODE. SO LONG AS THE INPUT SIGNAL REVERSE BIASES THIS DIODE, THE GATE HAS VERY HIGH INPUT RESISTANCE.)

3. LIKE BIPOLAR TRANSISTORS, JFETs CAN BE DAMAGED OR DESTROYED BY EXCESSIVE CURRENT OR VOLTAGE.

☐ KINDS OF JUNCTION FETs — JFETs ARE USED IN MANY DIFFERENT APPLICATIONS. SINCE THEY CANNOT BE USED FOR HIGH POWER ROLES, MOST ARE INSTALLED IN SMALL PLASTIC OR METAL PACKAGES. HERE ARE THE MAIN CATEGORIES:

SMALL SIGNAL AND SWITCHING.

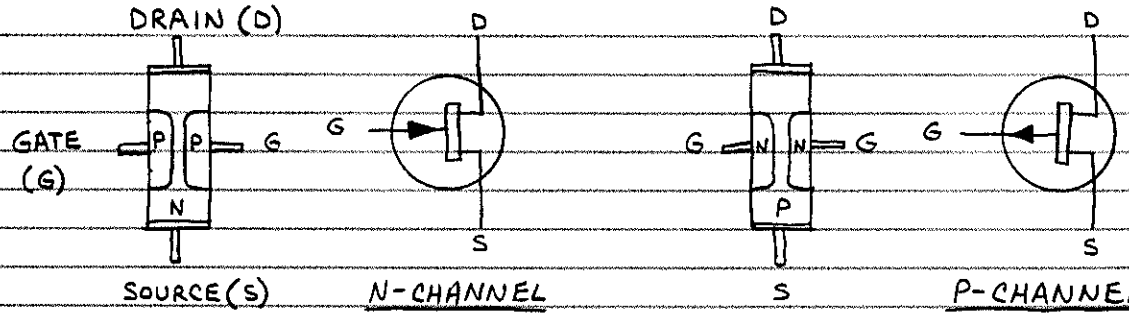


SMALL SIGNAL JFETs ARE USED AT THE INPUT STAGE OF AMPLIFIERS TO PROVIDE A HIGH RESISTANCE INPUT. THEY ARE ALSO USED AS SWITCHES.

HIGH FREQUENCY.

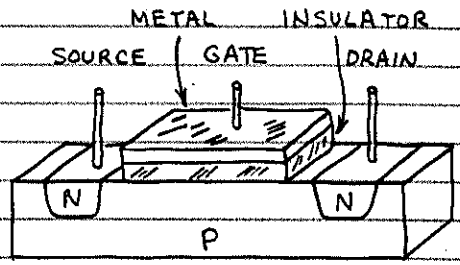
HIGH FREQUENCY JFETS ARE USED TO AMPLIFY OR PRODUCE HIGH FREQUENCY SIGNALS.

☐ JUNCTION FET SYMBOLS — GATES INTERNALLY CONNECTED.

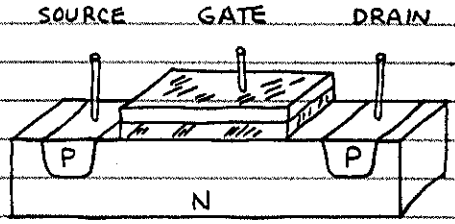


METAL-OXIDE-SEMICONDUCTOR FETs

THE METAL-OXIDE-SEMICONDUCTOR FET (OR MOSFET) HAS BECOME THE MOST IMPORTANT TRANSISTOR. MOST MICROCOMPUTER AND MEMORY INTEGRATED CIRCUITS ARE ARRAYS OF THOUSANDS OF MOSFETs ON A SMALL SLIVER OF SILICON. WHY? MOSFETs ARE EASY TO MAKE, THEY CAN BE VERY SMALL, AND SOME MOSFET CIRCUITS CONSUME NEGLIGIBLE POWER. NEW KINDS OF POWER MOSFETs ARE ALSO VERY USEFUL.

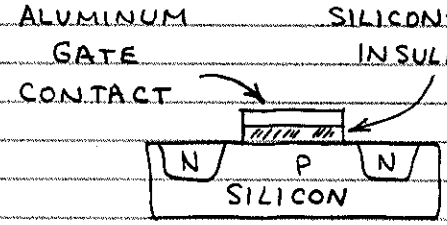


N-MOSFET

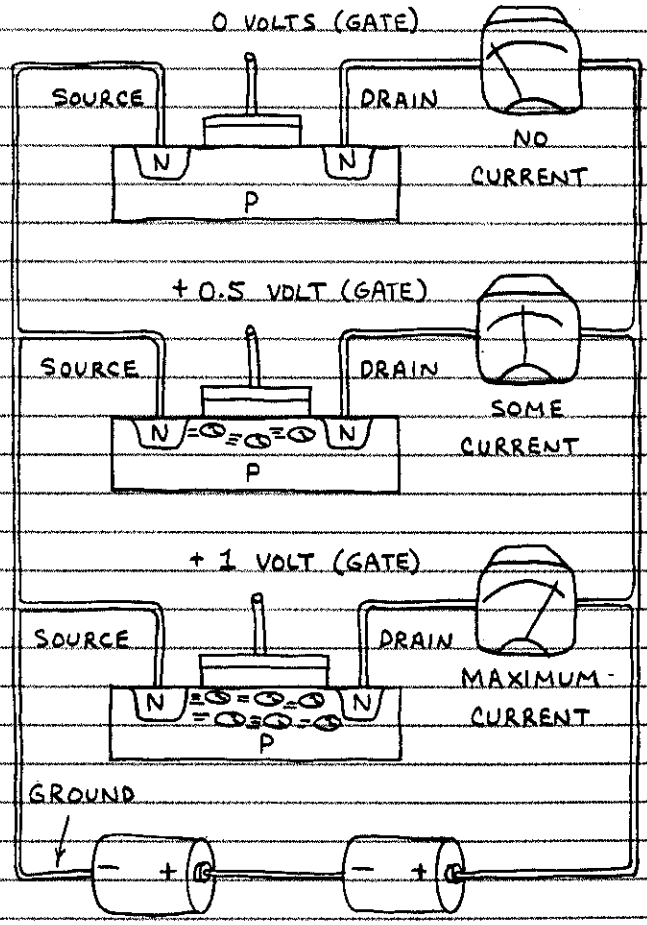


P-MOSFET

☐ MOSFET OPERATION— ALL MOSFETs ARE N-TYPE OR P-TYPE. UNLIKE THE JUNCTION FET, THE GATE OF A MOSFET HAS NO ELECTRICAL CONTACT WITH THE SOURCE AND DRAIN. A GLASS-LIKE LAYER OF SILICON-DIOXIDE (AN INSULATOR) SEPARATES THE GATE'S METAL CONTACT FROM THE REST OF THE TRANSISTOR.



A POSITIVE GATE VOLTAGE ATTRACTS ELECTRONS TO THE REGION BELOW THE GATE. THIS CREATES A THIN N-TYPE CHANNEL IN THE P-TYPE SILICON BETWEEN THE SOURCE AND DRAIN. CURRENT CAN THEN FLOW THROUGH THE CHANNEL. THE GATE VOLTAGE DETERMINES THE RESISTANCE OF THE CHANNEL.



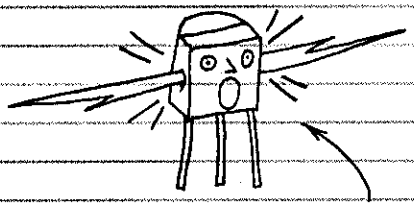
☐ MORE ABOUT MOSFETs — THE INPUT RESISTANCE OF THE MOSFET IS THE HIGHEST OF ANY TRANSISTOR. THIS AND OTHER FACTORS GIVE MOSFETs IMPORTANT ADVANTAGES:

1. THE GATE-CHANNEL RESISTANCE IS ALMOST INFINITE (TYPICALLY 1,000,000,000,000,000 - OHMS). THIS MEANS THE GATE PULLS NO CURRENT FROM EXTERNAL CIRCUITS. (WELL, IT MAY BORROW A FEW TRILLIONTHS OF AN AMPERE.)

2. MOSFETs CAN FUNCTION AS VOLTAGE-CONTROLLED VARIABLE RESISTORS. THE GATE VOLTAGE CONTROLS CHANNEL RESISTANCE.

3. NEW KINDS OF MOSFETs CAN SWITCH VERY HIGH CURRENTS IN A FEW BILLIONTHS OF A SECOND.

☐ CAUTION — BECAUSE THE GLASS-LIKE SILICON OXIDE LAYER BELOW THE GATE IS SO THIN, IT CAN BE PIERCED BY TOO MUCH VOLTAGE OR EVEN STATIC ELECTRICITY. EVEN THE STATIC CHARGE GENERATED BY CLOTHING OR A CELLOPHANE WRAPPER CAN ZAP THE GATE OF A MOSFET!

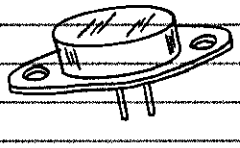


ZAPPED MOSFET

CAUTION SYMBOL

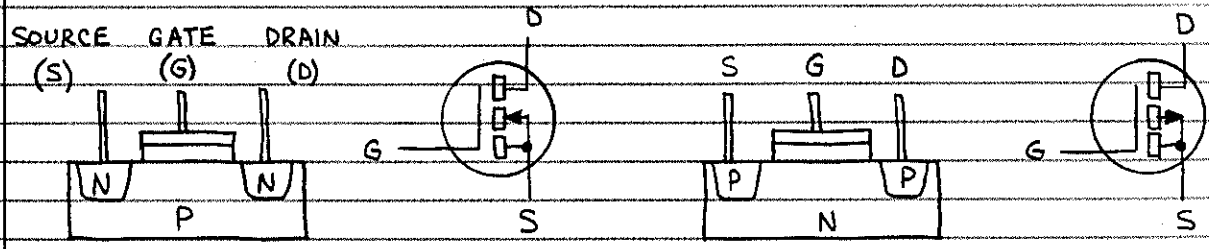
☐ KINDS OF MOSFETs — LIKE JFETs, MOSFETs INSTALLED IN SMALL METAL OR PLASTIC PACKAGES ARE USED TO GIVE AMPLIFIERS AN ULTRA-HIGH INPUT RESISTANCE. THEY ARE ALSO USED AS VOLTAGE CONTROLLED RESISTORS AND SWITCHES. THE MOST IMPORTANT CATEGORY HAS BECOME:

POWER.



POWER MOSFETs ALLOW A FEW VOLTS TO SWITCH OR AMPLIFY MANY AMPERES AT VERY FAST SPEEDS.

☐ MOSFET SYMBOLS — THESE ARE THE MOST COMMON.

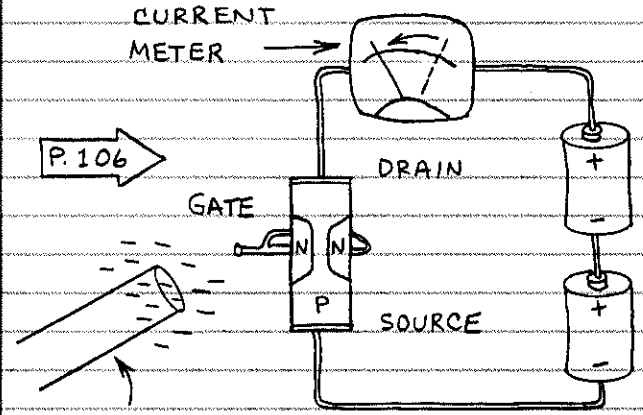


N-MOSFET P-MOSFET

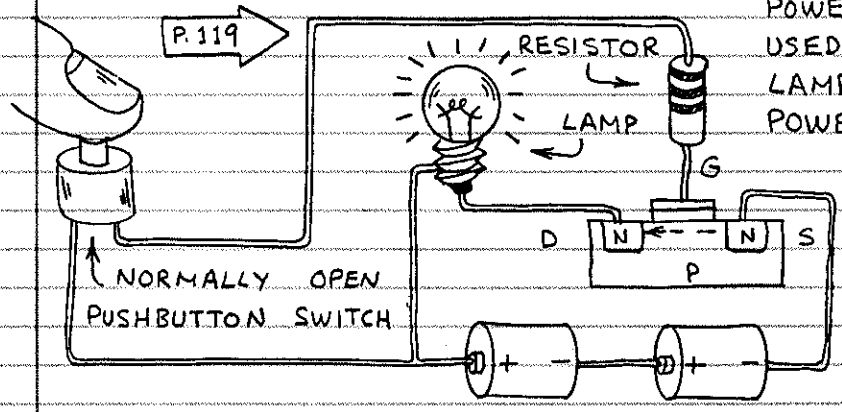
HOW FETs ARE USED

FIELD-EFFECT TRANSISTORS ARE USED AS AMPLIFIERS, SWITCHES AND VOLTAGE-CONTROLLED RESISTORS. HERE ARE SOME TYPICAL CIRCUIT ARRANGEMENTS.

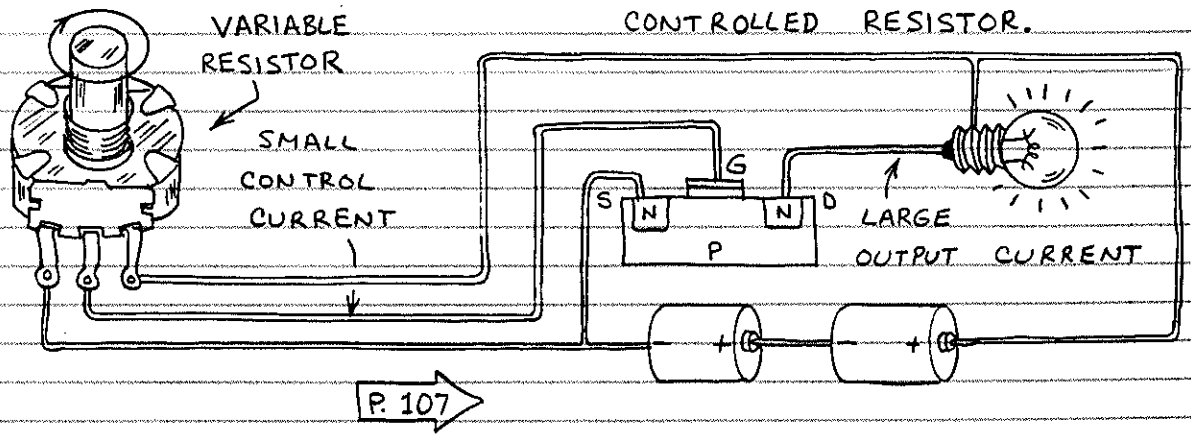
☐ A JFET ELECTROMETER — THIS ULTRA-SIMPLE CIRCUIT IS THE ELECTRONIC VERSION OF THE ELECTROSCOPE. THE GATE LEAD OF AN N-CHANNEL JFET IS LEFT DISCONNECTED. NORMALLY A CURRENT FLOWS FROM SOURCE TO DRAIN. WHEN A NEGATIVELY CHARGED OBJECT (LIKE A PLASTIC COMB THAT'S BEEN STROKED THROUGH YOUR HAIR) IS PLACED NEAR THE GATE, THE CURRENT FLOW IS REDUCED OR STOPPED.



☐ A MOSFET LAMP DRIVER — THIS CIRCUIT SHOWS HOW A POWER MOSFET CAN BE USED TO SWITCH ON A LAMP OR OTHER DC POWERED DEVICE. SINCE THE POWER MOSFET HAS AN ALMOST INFINITE INPUT RESISTANCE, THE SWITCH CAN BE REPLACED BY A TINY INPUT SIGNAL.



☐ A MOSFET LAMP DIMMER — THIS CIRCUIT USES A POWER MOSFET AS A VOLTAGE CONTROLLED RESISTOR.



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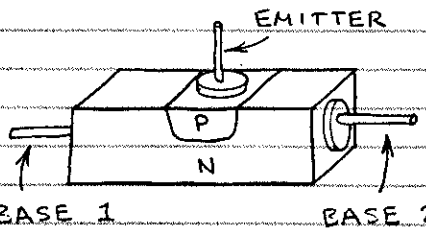
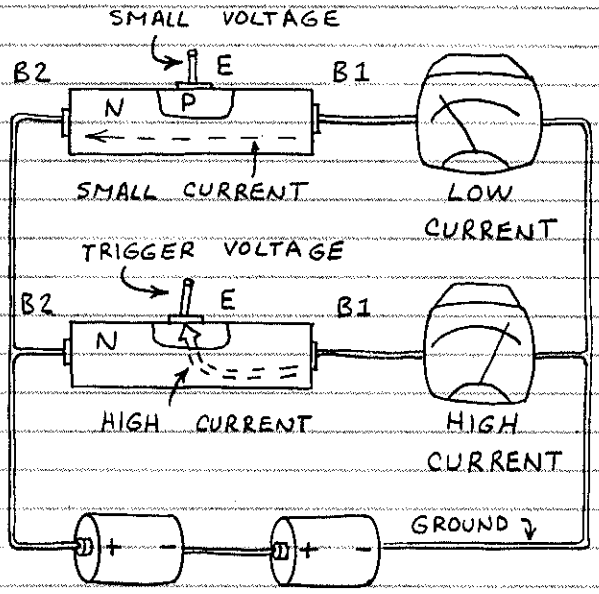
THE UNIJUNCTION TRANSISTOR

THE UNIJUNCTION TRANSISTOR (UJT) IS NOT A TRUE TRANSISTOR. IT'S MORE LIKE A DIODE WITH TWO CATHODE CONNECTIONS. IT WORKS LIKE A VOLTAGE-CONTROLLED SWITCH AND DOES NOT AMPLIFY.



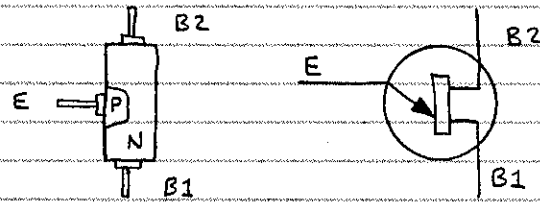
☐ UJT OPERATION —

NORMALLY A SMALL CURRENT WILL FLOW FROM BASE 1 TO BASE 2. WHEN THE VOLTAGE APPLIED TO THE EMITTER REACHES A CERTAIN THRESHOLD (SEVERAL VOLTS), THE UJT SWITCHES ON AND A HIGH CURRENT FLOWS FROM BASE 1 TO THE EMITTER. BELOW THE THRESHOLD VOLTAGE, NO CURRENT FLOWS FROM BASE 1 TO THE EMITTER.



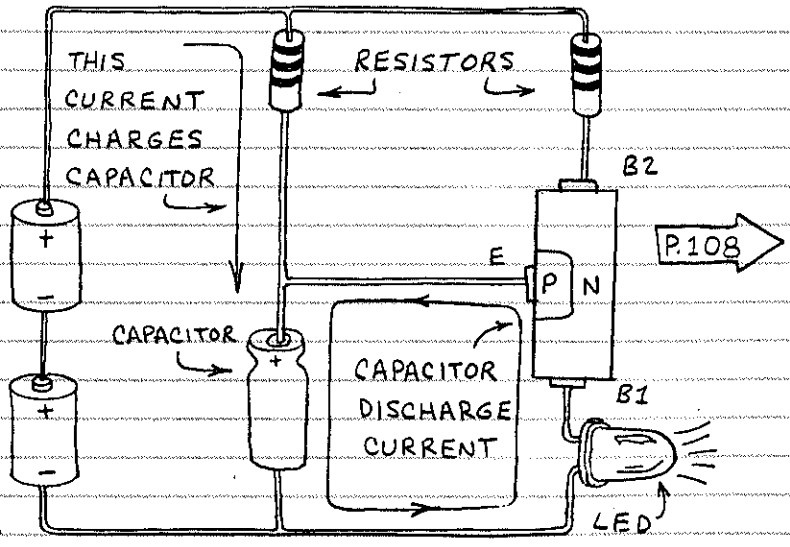
☐ UJT SYMBOL —

THE SYMBOL FOR THE UJT RESEMBLES THAT OF A JFET.

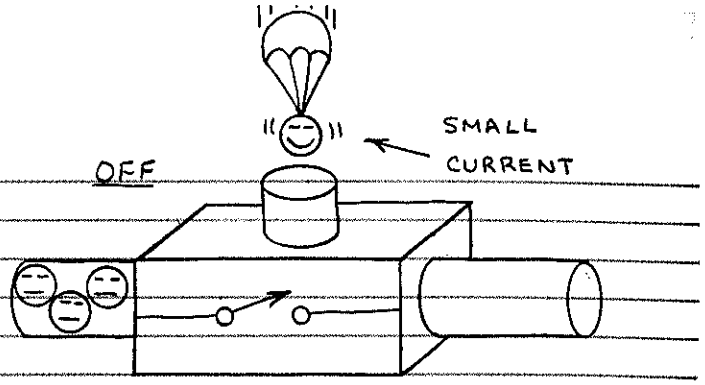


HOW UNIJUNCTION TRANSISTORS ARE USED

THIS ARRANGEMENT ALLOWS A UJT TO FLASH A LIGHT-EMITTING DIODE (LED). CURRENT FLOWS INTO THE CAPACITOR UNTIL THE UJT'S TRIGGER VOLTAGE IS REACHED. THE CURRENT IN THE CAPACITOR IS THEN "DUMPED" THROUGH THE LED. THE LED GLOWS UNTIL THE CAPACITOR IS DISCHARGED. THE CHARGE-DISCHARGE CYCLE THEN REPEATS.



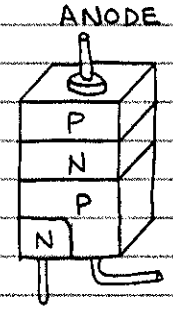
THE THYRISTOR



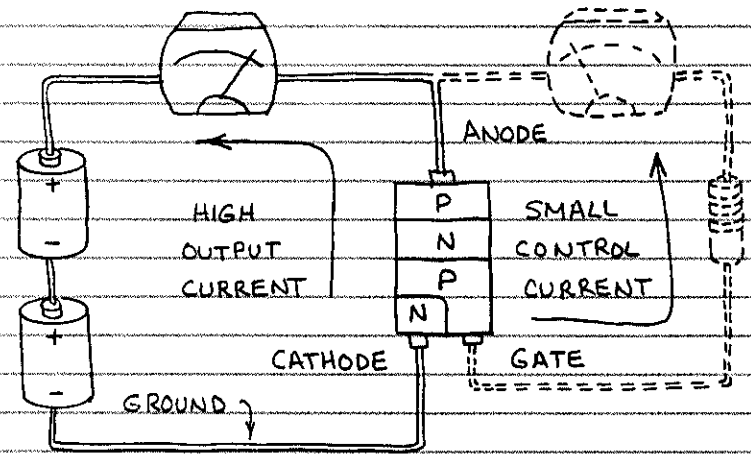
THYRISTORS ARE SEMICONDUCTOR DEVICES WITH THREE LEADS. A SMALL CURRENT AT ONE LEAD WILL ALLOW A MUCH LARGER CURRENT TO FLOW THROUGH THE OTHER TWO LEADS. THE CONTROLLED CURRENT IS EITHER ON OR OFF. THEREFORE THYRISTORS DO NOT AMPLIFY FLUCTUATING SIGNALS LIKE TRANSISTORS DO. INSTEAD THEY ARE SOLID-STATE SWITCHES. THERE ARE TWO FAMILIES OF THYRISTORS, SILICON-CONTROLLED RECTIFIERS (SCRs) AND TRIACs. SCRs SWITCH DIRECT CURRENT AND TRIACs SWITCH ALTERNATING CURRENT.

SILICON-CONTROLLED RECTIFIERS (SCRs)

THE SCR IS SIMILAR TO A BIPOLAR TRANSISTOR WITH A FOURTH LAYER AND THEREFORE THREE PN JUNCTIONS. IT IS SOMETIMES CALLED A 4-LAYER PNPN DIODE SINCE IT PASSES A CURRENT IN ONLY ONE DIRECTION.

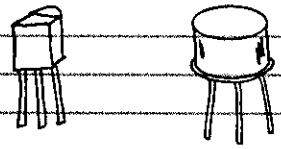


☐ SCR OPERATION — IF THE ANODE OF AN SCR IS MADE MORE POSITIVE THAN THE CATHODE THE TWO OUTERMOST PN JUNCTIONS ARE FORWARD BIASED. THE MIDDLE PN JUNCTION, HOWEVER, IS REVERSE BIASED AND CURRENT CANNOT FLOW. A SMALL GATE CURRENT FORWARD BIASES THE MIDDLE PN JUNCTION AND ALLOWS A MUCH LARGER CURRENT TO FLOW THROUGH THE DEVICE. THE SCR STAYS ON EVEN IF THE GATE CURRENT IS REMOVED! (UNTIL POWER IS DISCONNECTED.)



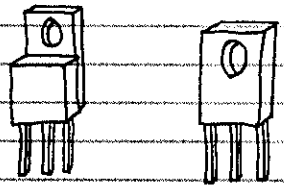
☐ KINDS OF SCRs — SCRs ARE CATEGORIZED ACCORDING TO THE CURRENT THEY CAN SWITCH. HERE ARE THREE GENERAL CATEGORIES (MANY OTHER CASE STYLES ARE AVAILABLE):

LOW CURRENT.



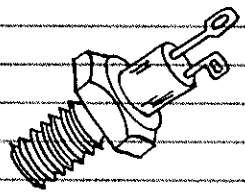
LOW CURRENT SCRs INCLUDE THOSE THAT SWITCH UP TO 1-AMPERE AT UP TO 100-VOLTS.

MEDIUM CURRENT.



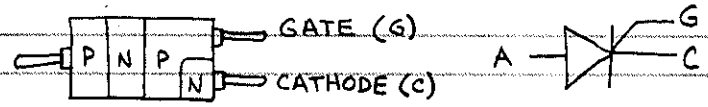
THESE SCRs SWITCH UP TO 10-AMPERES AT UP TO SEVERAL HUNDRED VOLTS. ONE COMMON USE IS SOLID-STATE SWITCHING FOR AUTO ENGINES.

HIGH CURRENT.



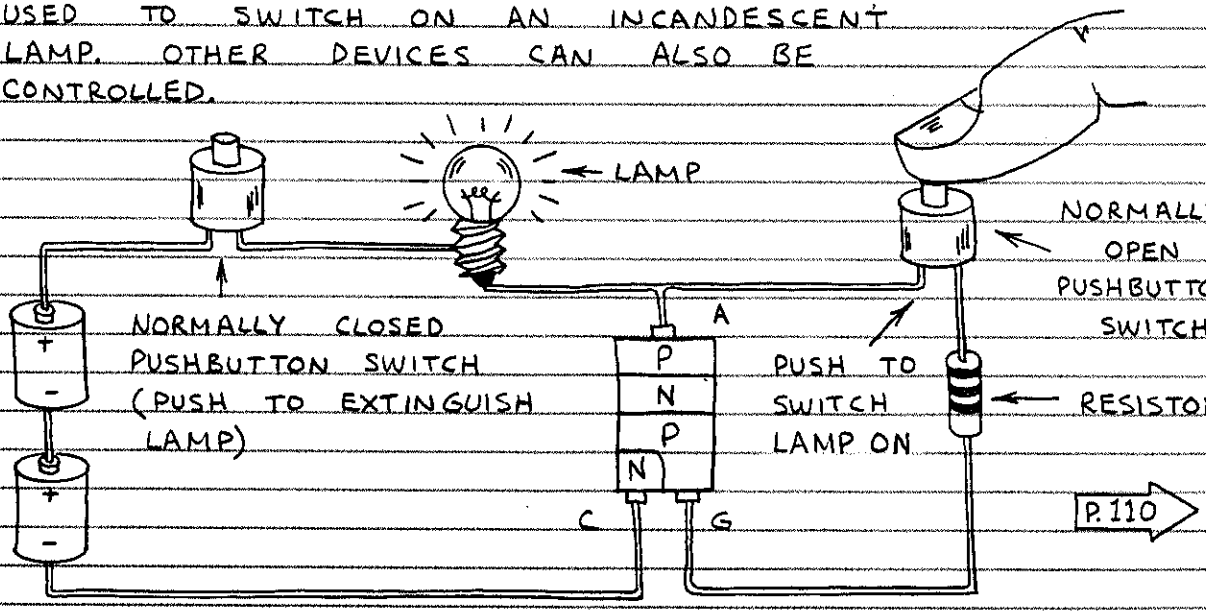
THESE SCRs CAN SWITCH UP TO 2,500-AMPERES AT UP TO SEVERAL THOUSAND VOLTS! THEY CONTROL MOTORS, LIGHTS, APPLIANCES, ETC.

☐ SCR SYMBOL.



HOW SCRs ARE USED

THIS ARRANGEMENT SHOWS HOW AN SCR IS USED TO SWITCH ON AN INCANDESCENT LAMP. OTHER DEVICES CAN ALSO BE CONTROLLED.



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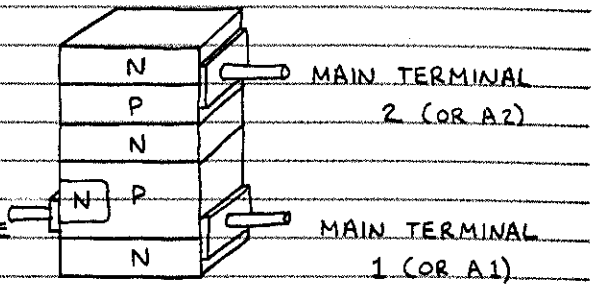
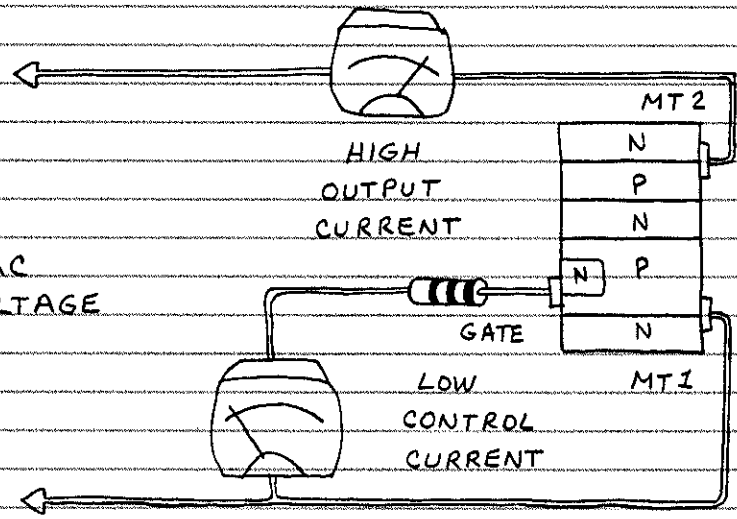
TRIACS

THE TRIAC IS EQUIVALENT TO TWO SCRs CONNECTED IN PARALLEL. THIS MEANS TRIACS CAN SWITCH BOTH DIRECT AND ALTERNATING CURRENT. NOTICE THAT THE TRIAC HAS FIVE LAYERS PLUS AN EXTRA N-TYPE REGION. ALSO NOTE HOW ALL THREE LEADS MAKE CONTACT WITH TWO LAYERS.

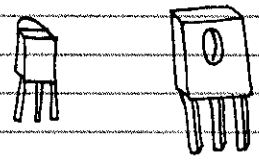


☐ TRIAC OPERATION — THE TWO PARALLEL SCRs THAT FORM A TRIAC FACE IN OPPOSITE DIRECTIONS (REVERSE-PARALLEL). WHEN USED TO SWITCH ALTERNATING CURRENT, THE TRIAC STAYS ON ONLY WHEN THE GATE RECEIVES CURRENT. REMOVE THE GATE CURRENT AND IT SWITCHES OFF WHEN THE AC PASSES THROUGH 0 VOLTS.



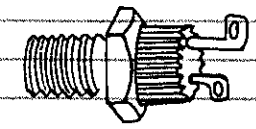
☐ KINDS OF TRIACS — TRIACS, LIKE SCRs, ARE CATEGORIZED ACCORDING TO THE CURRENT THEY CAN SWITCH. TRIACS DON'T HAVE THE VERY HIGH POWER CAPABILITY OF HIGH CURRENT SCRs. HERE ARE TWO CATEGORIES:

LOW CURRENT.



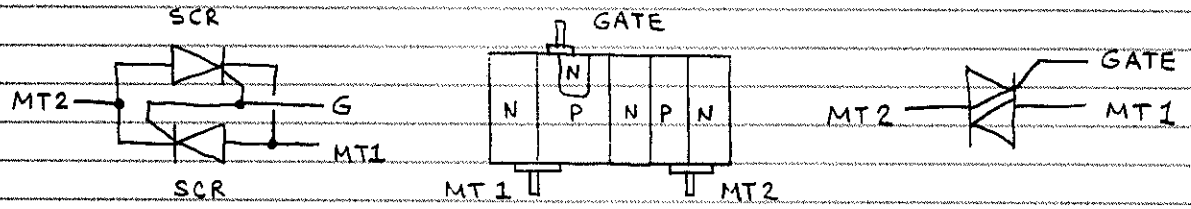
LOW CURRENT TRIACS SWITCH UP TO 1-AMPERE AT UP TO SEVERAL HUNDRED VOLTS. OTHER CASE STYLES ALSO USED.

MEDIUM CURRENT.



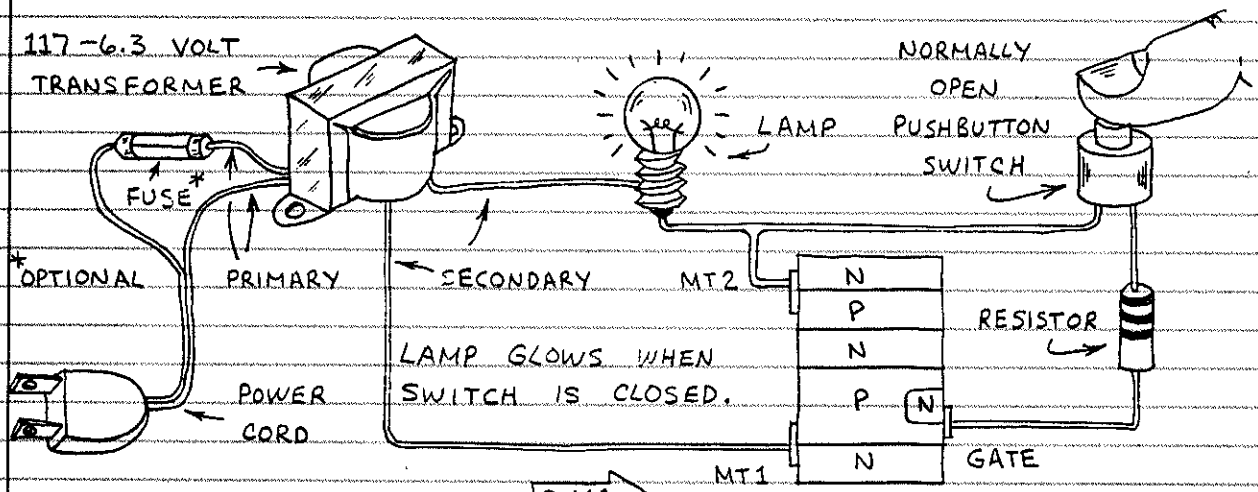
THESE TRIACS SWITCH UP TO 40-AMPERES AT UP TO 1,000-VOLTS. MANY CASE STYLES ARE AVAILABLE.

☐ TRIAC SYMBOL — REMEMBER, THE TRIAC IS THE SAME AS TWO REVERSE-PARALLEL SCRs:



HOW TRIACS ARE USED

THIS ARRANGEMENT SHOWS HOW A TRIAC CAN SWITCH ON A LAMP POWERED BY HOUSEHOLD LINE CURRENT. MOTORS AND OTHER DEVICES CAN ALSO BE CONTROLLED.

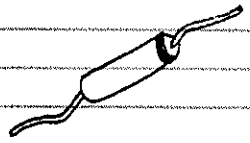


CAUTION: DO NOT ASSEMBLE. P.111

TWO-LEAD THYRISTORS

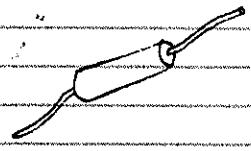
AN SCR OR TRIAC WILL SWITCH ON <u>WITHOUT</u> A GATE SIGNAL IF THE VOLTAGE ACROSS ITS OTHER TWO LEADS REACHES A CERTAIN LEVEL (THE <u>BREAKDOWN VOLTAGE</u>). THIS SELF-SWITCHING ABILITY MAKES POSSIBLE TWO-LEAD THYRISTORS.

FOUR-LAYER DIODE.



A FOUR-LAYER DIODE IS AN SCR WITHOUT A GATE. IT SWITCHES DC VOLTAGE.

DIAC.



A DIAC IS A THREE-LAYER DEVICE SIMILAR TO A PNP JUNCTION TRANSISTOR WITHOUT A BASE LEAD. IT SWITCHES AC VOLTAGE.