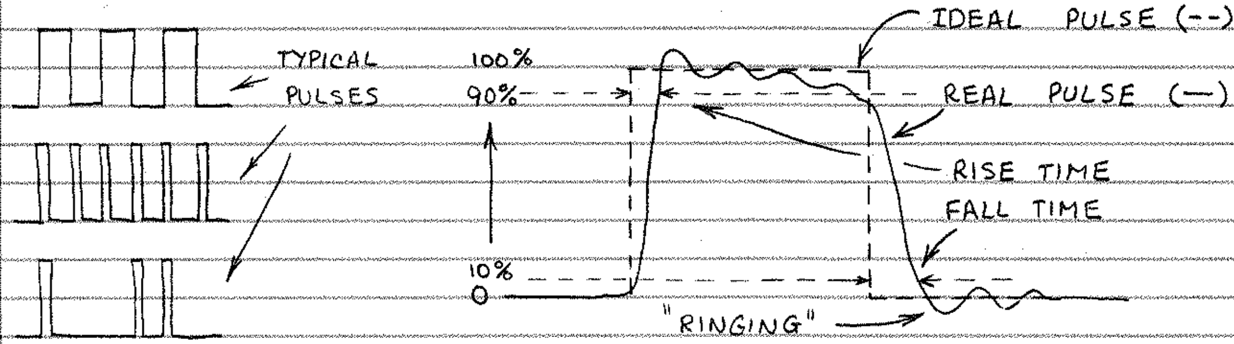
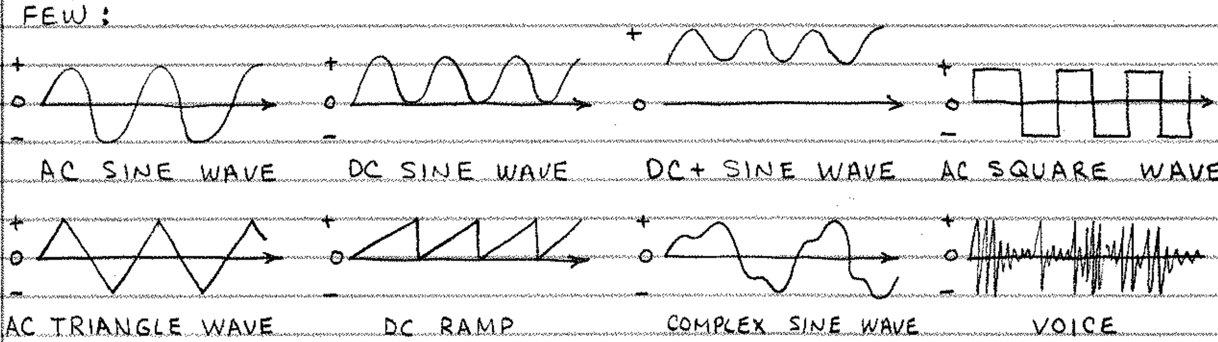
☐ PULSES — A PULSE IS A SUDDEN, BRIEF INCREASE OR DECREASE IN A CURRENT FLOW. THE IDEAL PULSE WOULD HAVE AN INSTANTANEOUS RISE AND FALL, BUT REAL PULSES ARE NOT SO IDEAL.

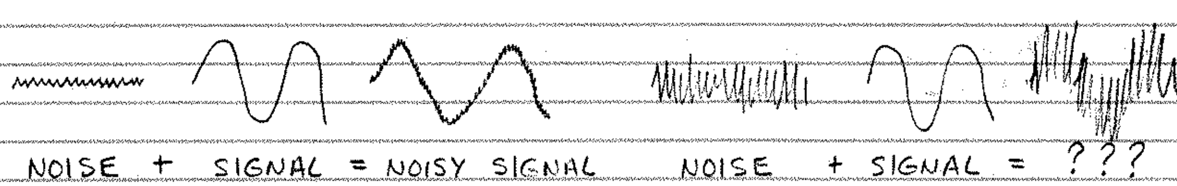


☐ WAVES — A WAVE IS A PERIODIC FLUCTUATION IN A CURRENT OR VOLTAGE. WAVES MAY HAVE A SINGLE POLARITY (DC) OR BOTH POSITIVE AND NEGATIVE COMPONENTS (AC). THERE ARE MANY KINDS OF WAVES. HERE ARE A FEW:



☐ SIGNALS — A SIGNAL IS A PERIODIC WAVEFORM THAT CONVEYS INFORMATION. THE PROCESS THAT GENERATES THE WAVEFORM IS CALLED MODULATION. SIGNALS CAN BE AC, DC OR AC RIDING ON A DC LEVEL. THEIR ENEMY IS...

☐ NOISE — ALL ELECTRONIC DEVICES AND CIRCUITS GENERATE SMALL, RANDOM ELECTRICAL CURRENTS. WHEN THESE CURRENTS ARE UNWANTED, THEY'RE CALLED NOISE. NOISE CAN ALSO ENTER ELECTRONIC CIRCUITS BY MEANS OF THE ELECTROMAGNETIC WAVES GENERATED BY LIGHTNING, AUTOMOBILE IGNITION SYSTEMS, ELECTRIC MOTORS AND POWER LINES. WHILE NOISE MAY HAVE A LEVEL OF ONLY A FEW MILLIONTHS OF A VOLT OR AMPERE, IT MAY EASILY OBSCURE AN EQUALLY LOW LEVEL SIGNAL.

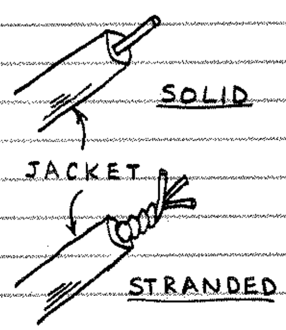


2. ELECTRONIC COMPONENTS

DOZENS OF DIFFERENT FAMILIES OF PARTS AND COMPONENTS BLOCK, CARRY, CONTROL, SELECT, STEER, SWITCH, STORE, MANIPULATE, REPLICATE, MODULATE AND EXPLOIT AN ELECTRICAL CURRENT. THOSE THAT USE SEMICONDUCTING CRYSTALS ARE SO IMPORTANT WE'LL DEVOTE AN ENTIRE CHAPTER TO THEM. YOU'LL FIND JUST ABOUT ALL THE REMAINING PARTS YOU SHOULD KNOW ABOUT IN THIS CHAPTER.

WIRE AND CABLE

USED TO CARRY AN ELECTRICAL CURRENT. MOST WIRE IS MADE FROM A LOW RESISTANCE METAL LIKE COPPER. SOLID WIRE IS A SINGLE CONDUCTOR. STRANDED WIRE IS TWO OR MORE TWISTED OR BRAIDED BARE CONDUCTORS. MOST WIRE IS PROTECTED BY AN INSULATING COVERING OF PLASTIC, RUBBER OR LACQUER. WIRE WHICH HAS BEEN TINNED IS EASIER TO SOLDER.



SPECIFICATIONS FOR BARE COPPER WIRE

GAUGE	DIAMETER (INCHES)	FEET/POUND	FEET/OHM
16	.05082	127.9	249.00
18	.04030	203.4	156.50
20	.03196	323.4	98.50
22	.02535	514.2	61.96
24	.02010	817.7	38.96
26	.01594	1300.0	24.50
28	.01264	2067.0	15.41
30	.01003	3287.0	9.69

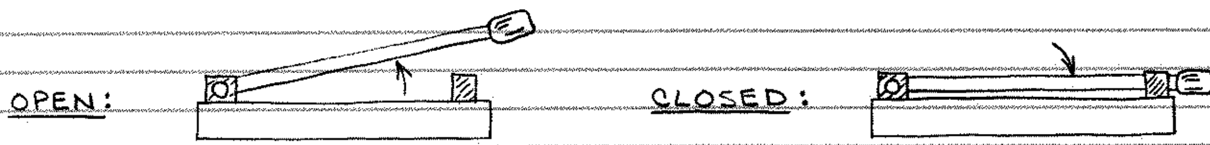
CABLES HAVE ONE OR MORE CONDUCTORS AND MORE IN-SULATION THAN ORDINARY WIRE. COAXIAL CABLE CAN CARRY HIGH FREQUENCY SIGNALS (LIKE TELEVISION).

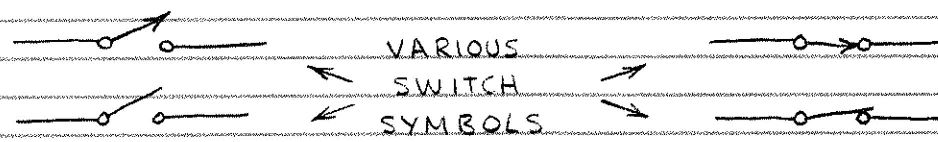
☐ CAUTION! ALWAYS USE WIRE RATED FOR THE CURRENT IT IS TO CARRY. IF A WIRE IS HOT TO THE TOUCH, IT'S CARRYING TOO MUCH CURRENT. USE A HEAVIER GAUGE WIRE OR REDUCE THE CURRENT. OTHERWISE...

SWITCHES

MECHANICAL SWITCHES PERMIT OR INTERRUPT THE FLOW OF CURRENT. THEY ARE ALSO USED TO DIRECT CURRENT TO VARIOUS POINTS.

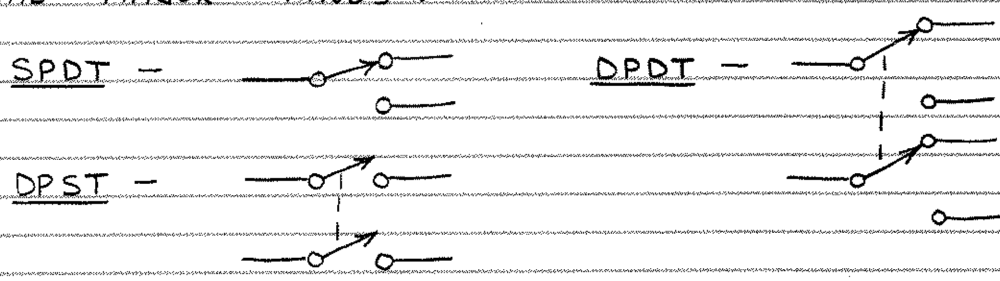
☐ THE BASIC KNIFE SWITCH — THE SIMPLEST SWITCH ...





THIS IS CALLED AN SPST (SINGLE-POLE, SINGLE-THROW) SWITCH.

☐ MULTIPLE CONTACT SWITCHES — HERE ARE SYMBOLS FOR THE MAJOR KINDS:

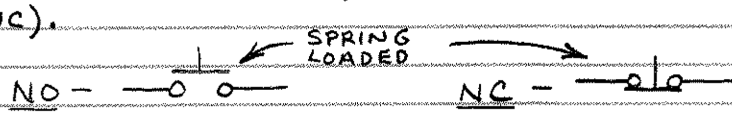


SPDT – SINGLE-POLE, DOUBLE-THROW
DPST – DOUBLE-POLE, SINGLE-THROW
DPDT – DOUBLE-POLE, DOUBLE-THROW

(THE DASHED LINE MEANS BOTH SIDES MOVE TOGETHER.)

☐ OTHER SWITCHES —

PUSHBUTTON. USUALLY SPST, NORMALLY OPEN (NO) OR NORMALLY CLOSED (NC).



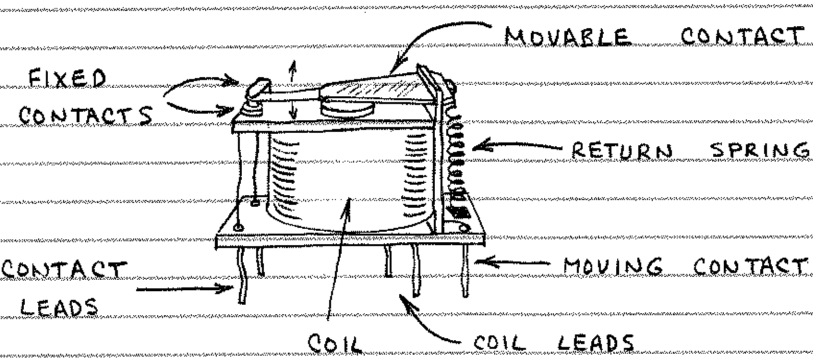
ROTARY. WAFER-LIKE WITH ONE POLE AND 2 OR MORE CONTACTS. WAFERS CAN BE STACKED TO PROVIDE MORE POLES. MANY VARIATIONS ARE POSSIBLE.

MERCURY. MERCURY BLOB CLOSES SWITCH. POSITION SENSITIVE.

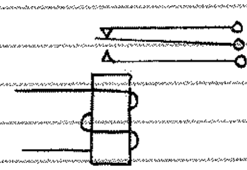
OTHER. MANY KINDS OF TOGGLE, ROCKER, LEVER, SLIDE, PUSH-ON/PUSH-OFF, ILLUMINATED AND OTHER SWITCHES ARE AVAILABLE.

RELAYS

A RELAY IS AN ELECTROMAGNETIC SWITCH. A SMALL CURRENT FLOWING THROUGH A COIL IN THE RELAY CREATES A MAGNETIC FIELD THAT PULLS ONE SWITCH CONTACT AGAINST OR AWAY FROM ANOTHER.

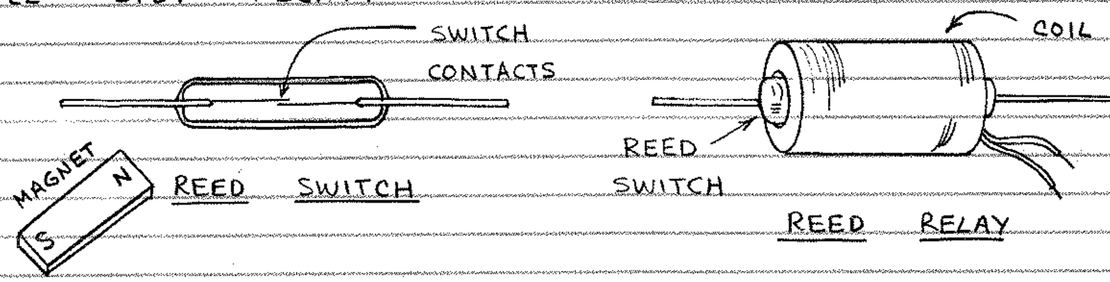


☐ RELAY SYMBOL — THE ARRANGEMENT OF CONTACTS CAN PROVIDE SPST, SPDT, DPST, DPDT AND OTHER SWITCH OPERATIONS.



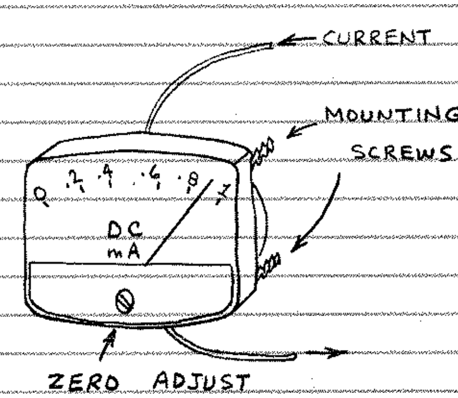
THIS IS THE SYMBOL FOR A RELAY WITH SPDT CONTACTS.

☐ REED SWITCH RELAYS — AN ENCLOSED GLASS TUBE HOUSING A PAIR OF CLOSELY SPACED SWITCH CONTACTS IS A REED SWITCH. A MAGNETIC FIELD WILL CLOSE THE CONTACTS. THIS MAKES POSSIBLE A VERY SIMPLE SPST RELAY.



MOVING COIL METER

A COIL ON A PIVOT BETWEEN THE POLES OF A U-SHAPED MAGNET WILL ROTATE WHEN A CURRENT IS PASSED THROUGH THE COIL. THIS IS THE PRINCIPLE OF THE MOVING COIL METER.



MICROPHONES AND SPEAKERS

A MICROPHONE CONVERTS SOUND WAVE VARIATIONS INTO CORRESPONDING VARIATIONS IN AN ELECTRICAL CURRENT. THE SOUND WAVE VARIATIONS ARE FIRST CONVERTED TO BACK-AND-FORTH MOVEMENTS OF A FLEXIBLE FILM OR FOIL CALLED A DIAPHRAGM. THESE MOVEMENTS THEN CAUSE VARIATIONS IN AN ELECTRICAL CURRENT BY ANY OF THE FOLLOWING MEANS:

☐ CARBON— MOVEMENT OF THE DIAPHRAGM CHANGES THE PRESSURE APPLIED TO A CAPSULE OF CARBON PARTICLES. THIS CAUSES PROPORTIONAL CHANGES IN THE RESISTANCE OF THE CAPSULE.

☐ DYNAMIC— A SMALL COIL IS MOVED THROUGH A MAGNETIC FIELD AS THE DIAPHRAGM MOVES. THIS CAUSES A PROPORTIONAL OUTPUT CURRENT TO BE GENERATED.

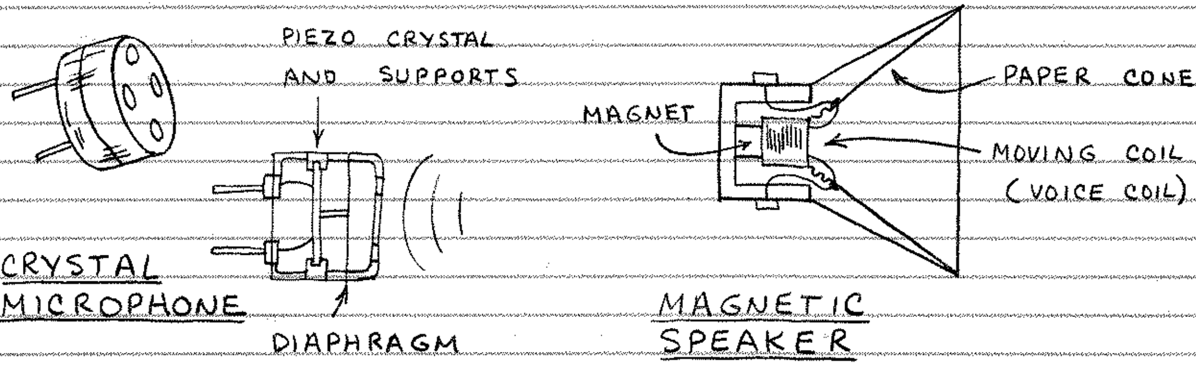
☐ CONDENSER— THE MOVING DIAPHRAGM ALTERS THE DISTANCE BETWEEN TWO METAL PLATES. THE RESULT IS A PROPORTIONAL CHANGE IN THE CAPACITANCE OF THE PLATES.

☐ CRYSTAL— A WAFER OF PIEZOELECTRIC MATERIAL (WHICH PRODUCES A VOLTAGE WHEN BENT BY THE PRESSURE OF SOUND WAVES) FORMS THE DIAPHRAGM OR IS MECHANICALLY LINKED TO THE DIAPHRAGM.

A SPEAKER CONVERTS VARIATIONS IN A CURRENT OR VOLTAGE INTO SOUND WAVES. THE TWO MOST COMMON SPEAKERS ARE:

☐ MAGNETIC— SIMILAR IN PRINCIPLE TO A DYNAMIC MICROPHONE. IN FACT, A MAGNETIC SPEAKER CAN BE USED AS A MICROPHONE.

☐ CRYSTAL— SIMILAR IN PRINCIPLE TO A CRYSTAL MICROPHONE. A CRYSTAL SPEAKER CAN DOUBLE AS A MICROPHONE.



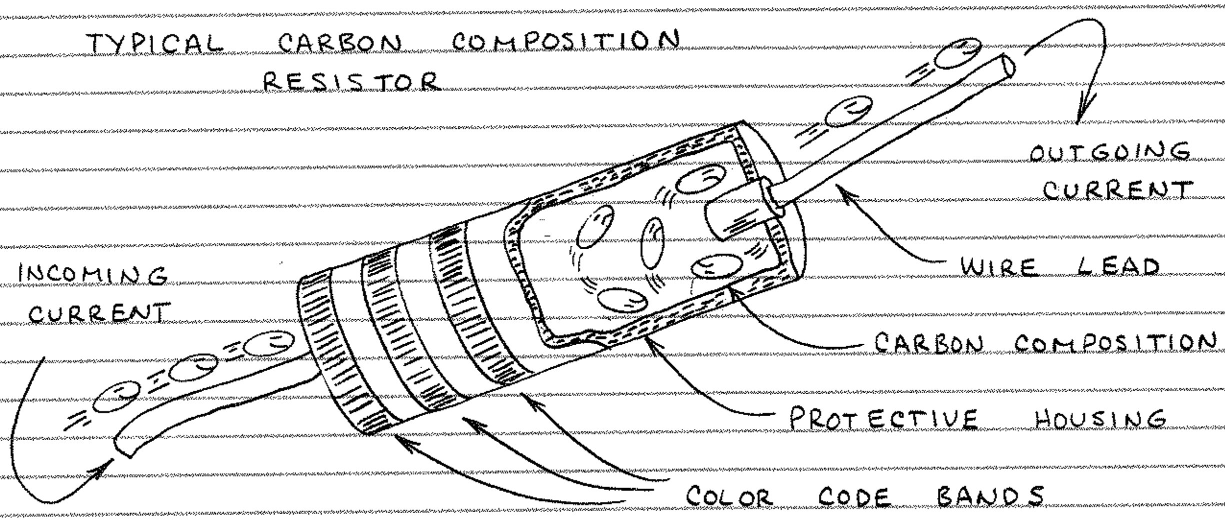
CRYSTAL MICROPHONE

MAGNETIC SPEAKER

RESISTORS

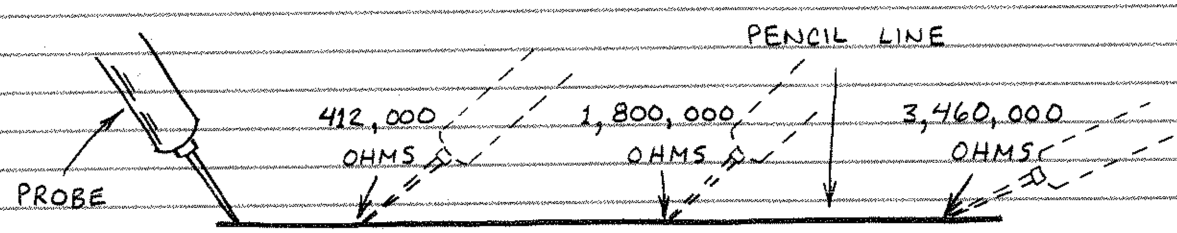
RESISTORS COME IN DOZENS OF SIZES AND SHAPES BUT THEY ALL DO THE SAME THING: LIMIT* CURRENT. MORE ABOUT THAT LATER. FIRST, LET'S SEE HOW A TYPICAL RESISTOR IS MADE:

*OR RESIST

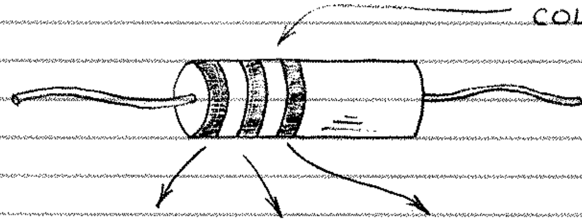


"CARBON COMPOSITION" IS JUST A FANCY WAY OF DESCRIBING POWDERED CARBON MIXED WITH A GLUE-LIKE BINDER. THIS KIND OF RESISTOR IS EASY TO MAKE. AND ITS RESISTANCE CAN BE CHANGED FROM ONE RESISTOR TO THE NEXT SIMPLY BY CHANGING THE RATIO OF CARBON PARTICLES TO BINDER. MORE CARBON GIVES LESS RESISTANCE.

☐ DO-IT-YOURSELF RESISTORS — YOU CAN MAKE A RESISTOR BY DRAWING A LINE WITH A SOFT LEAD PENCIL ON A SHEET OF PAPER. MEASURE THE RESISTANCE OF THE LINE OR POINTS ALONG IT BY TOUCHING THE PROBES OF A MULTIMETER TO THE LINE. BE SURE TO SET THE MULTIMETER TO ITS HIGHEST RESISTANCE SCALE. THE RESISTANCE OF A SINGLE LINE MAY BE TOO HIGH TO MEASURE. IF SO, DRAW OVER THE LINE A DOZEN OR SO TIMES. HERE'S WHAT I MEASURED:



☐ RESISTOR COLOR CODE — SEE THOSE COLOR CODE BANDS ON THE RESISTOR PICTORIAL? IN REAL LIFE THEY'RE KIND OF PRETTY. BUT THEY HAVE A FAR MORE IMPORTANT PURPOSE: THEY INDICATE THE RESISTANCE OF THE RESISTOR THEY DECORATE. HERE'S HOW:



COLOR	1	2	3 (MULTIPLIER)
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1,000
YELLOW	4	4	10,000
GREEN	5	5	100,000
BLUE	6	6	1,000,000
VIOLET	7	7	10,000,000
GRAY	8	8	100,000,000
WHITE	9	9	(NONE)

NOTE: SOMETIMES THERE'S A FOURTH BAND. IT INDICATES THE TOLERANCE* OF THE RESISTOR:

GOLD = ±5%
SILVER = ±10%
NONE = ±20%

* OR ACCURACY

LOOKS COMPLICATED THE FIRST TIME... BUT YOU'LL QUICKLY LEARN HOW TO USE IT. FOR EXAMPLE, WHAT'S THE RESISTANCE OF A RESISTOR COLOR CODED YELLOW, VIOLET AND RED? YELLOW IS THE FIRST COLOR SO THE FIRST NUMBER IS 4. VIOLET IS THE SECOND COLOR SO THE SECOND NUMBER IS 7. SINCE THE THIRD COLOR IS RED, THE MULTIPLIER IS 100. THEREFORE, THE RESISTANCE IS 47 × 100 OR 4700 OHMS. NO FOURTH COLOR BAND MEANS THE ACTUAL RESISTANCE IS 4700 ± 20%. 20% OF 4700 IS 940. THEREFORE, THE ACTUAL VALUE IS BETWEEN 3760 AND 5640 OHMS.

☐ SUBSTITUTING RESISTORS — WHAT IF YOU NEED A 6700-OHM RESISTOR BUT CAN ONLY FIND A 6800-OHM UNIT? YOU CAN ALMOST ALWAYS USE ANY VALUE WITHIN 10 OR 20% OF THE REQUIRED VALUE SO GO AHEAD AND USE IT. IF A PARTICULAR CIRCUIT REQUIRES MORE ACCURACY IT WILL TELL YOU. OF COURSE YOU CAN BUILD UP CUSTOM RESISTANCES BY CONNECTING TWO OR MORE RESISTORS IN SERIES OR IN PARALLEL. MORE ABOUT THAT LATER.

☐ RESISTOR SUBSTITUTION PRECAUTIONS — RESISTORS THAT CONDUCT LOTS OF CURRENT CAN BECOME VERY HOT! THEREFORE, ALWAYS USE RESISTORS HAVING THE PROPER POWER RATING. IF A PROJECT YOU'RE BUILDING DOESN'T SPECIFY THE POWER RATING FOR ITS RESISTORS, IT'S USUALLY OK TO USE 1/4 OR 1/2 WATT UNITS.

☐ SOME RESISTOR SHORTHAND — OFTEN YOU'LL SEE RESISTORS DESIGNATED WITH A K OR M SUFFIX, LIKE 47K OR 10M. K MEANS KILO, AFTER THE GREEK WORD FOR 1,000. THEREFORE, 47K MEANS 47 × 1,000 OR 47,000. M IS SHORT FOR MEGOHM OR 1,000,000 OHMS. THEREFORE A 1M RESISTOR HAS A RESISTANCE OF 1 × 1,000,000 OR 1,000,000 OHMS. SUMMING UP...

K = × 1,000 (47K = 47 × 1,000 = 47,000 OHMS)

M = × 1,000,000 (2.2M = 2.2 × 1,000,000 = 2,200,000 OHMS)

☐ OTHER KINDS OF RESISTORS — THE CARBON COMPOSITION RESISTOR IS ONLY ONE OF SEVERAL MAJOR KINDS OF RESISTORS. HERE ARE OTHERS:

METAL FILM RESISTORS. VARIOUS KINDS OF RESISTORS THAT USE A THIN FILM OF METAL OR A METAL PARTICLE MIXTURE TO ACHIEVE VARIOUS RESISTANCES.

CARBON FILM RESISTORS. THESE ARE MADE BY DEPOSITING A CARBON FILM ON A SMALL CERAMIC CYLINDER. A SPIRAL GROOVE CUT INTO THE FILM CONTROLS THE LENGTH OF CARBON BETWEEN THE LEADS, HENCE THE RESISTANCE.

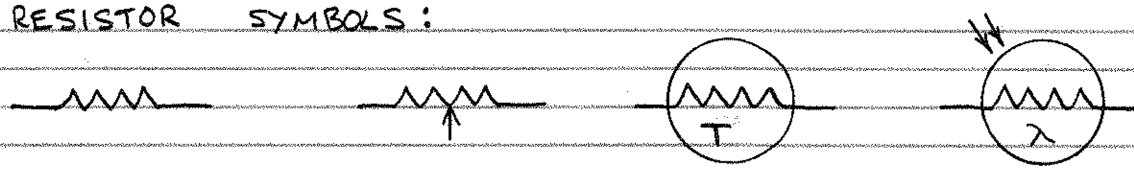
WIRE-WOUND RESISTORS. THESE CONSIST OF A TUBULAR FORM WRAPPED WITH COILS OF RESISTANCE WIRE. THEY ARE VERY ACCURATE AND CAN TAKE LOTS OF HEAT.

PHOTORESISTORS. ALSO CALLED PHOTOCELLS. MADE FROM A LIGHT SENSITIVE MATERIAL LIKE CADMIUM SULFIDE. INCREASING THE LIGHT LEVEL DECREASES THE RESISTANCE. MORE ABOUT THIS LATER.

THERMISTORS. THIS IS A TEMPERATURE SENSITIVE RESISTOR. INCREASING THE TEMPERATURE DECREASES THE RESISTANCE (IN MOST CASES).

☐ VARIABLE RESISTORS — OFTEN IT'S NECESSARY TO CHANGE THE RESISTANCE OF A RESISTOR. VARIABLE RESISTORS ARE CALLED POTENTIOMETERS. THEY ARE USED TO ALTER THE VOLUME OF A RADIO, CHANGE THE BRIGHTNESS OF A LAMP, ADJUST THE CALIBRATION OF A METER, ETC. TRIMMERS ARE POTENTIOMETERS EQUIPPED WITH A PLASTIC THUMBWHEEL OR A SLOT FOR A SCREWDRIVER BLADE. THEY ARE DESIGNED FOR OCCASIONAL ADJUSTMENT.

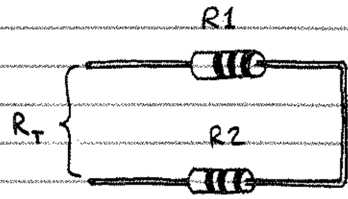
☐ RESISTOR SYMBOLS:



FIXED RESISTOR   POTENTIOMETER   THERMISTOR   PHOTORESISTOR

HOW RESISTORS ARE USED

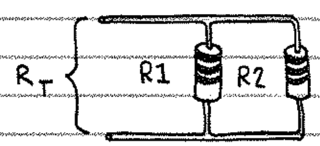
☐ SERIES CIRCUIT — OFTEN RESISTORS ARE CONNECTED IN SERIES LIKE THIS:



THE TOTAL RESISTANCE IS SIMPLY THE SUM OF THE INDIVIDUAL RESISTANCES.

$$R_T = R1 + R2$$

☐ PARALLEL CIRCUIT — RESISTORS CAN ALSO BE CONNECTED IN PARALLEL LIKE THIS:



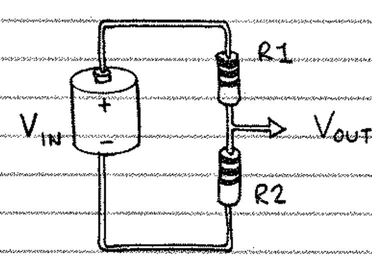
THE TOTAL RESISTANCE IS THE PRODUCT OF THE TWO RESISTANCES DIVIDED BY THEIR SUM.

$$R_T = \frac{R1 \times R2}{R1 + R2}$$

FOR THREE OR MORE IN PARALLEL, GO FIND YOUR CALCULATOR BECAUSE...

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \ldots \text{ETC.}}$$

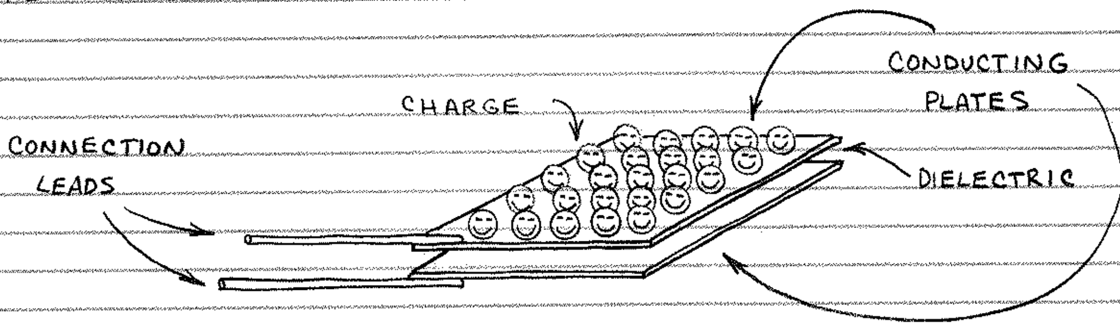
☐ VOLTAGE DIVISION — SUPER IMPORTANT! V_{OUT} IS DETERMINED BY RATIO OF R1 AND R2. HERE'S THE FORMULA:



$$V_{OUT} = V_{IN}\left(\frac{R2}{R1 + R2}\right)$$

CAPACITORS

THERE ARE MANY KINDS OF CAPACITORS, BUT THEY ALL DO THE SAME THING: STORE ELECTRONS. THE SIMPLEST CAPACITOR IS TWO CONDUCTORS SEPARATED BY AN INSULATING MATERIAL CALLED THE DIELECTRIC. LIKE THIS:

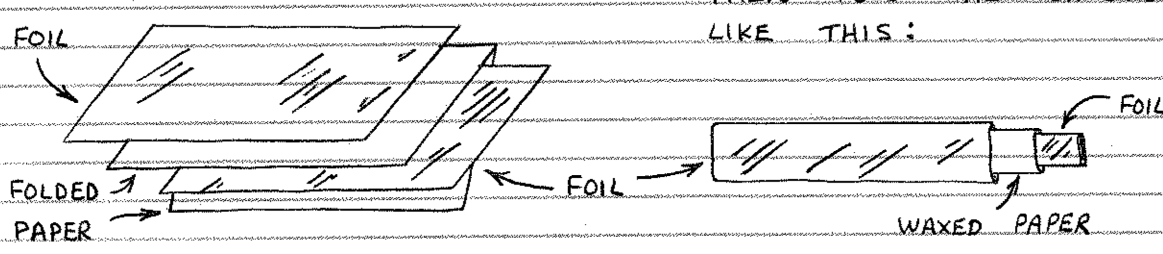


THE DIELECTRIC CAN BE PAPER, PLASTIC FILM, MICA, GLASS, CERAMIC, AIR OR A VACUUM. THE PLATES CAN BE ALUMINUM DISCS, ALUMINUM FOIL OR A THIN FILM OF METAL APPLIED TO OPPOSITE SIDES OF A SOLID DIELECTRIC. THE CONDUCTOR – DIELECTRIC – CONDUCTOR SANDWICH CAN BE ROLLED INTO A CYLINDER OR LEFT FLAT. MORE ABOUT TYPES OF CAPACITORS LATER.

HOW TO MAKE A CAPACITOR

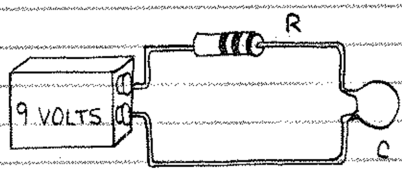
YOU CAN MAKE A CAPACITOR FROM TWO SHEETS OF ALUMINUM FOIL AND ONE SHEET OF WAXED PAPER. FOLD THE PAPER AROUND ONE FOIL SHEET AND STACK THE SHEETS LIKE THIS:

THEN FOLD THE SHEETS LIKE THIS:

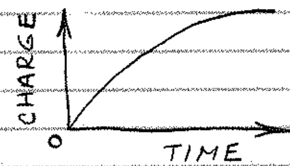


BE SURE THE FOIL SHEETS DON'T TOUCH! PRESS THE CONTACTS OF A 9-VOLT BATTERY BRIEFLY TO THE EXPOSED ENDS OF THE FOIL SHEETS. THEN TOUCH THE PROBES OF A HIGH-IMPEDANCE MULTIMETER TO THE FOIL SHEETS. THE METER WILL INDICATE A SMALL VOLTAGE FOR A FEW SECONDS. THE VOLTAGE WILL THEN FALL TO ZERO.

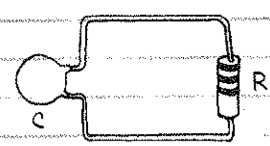
□ CHARGING A CAPACITOR — THE MINUS SIDE OF OUR HOMEMADE CAPACITOR IS CHARGED WITH ELECTRONS ALMOST IMMEDIATELY. SINCE RESISTORS LIMIT CURRENT YOU CAN SLOW DOWN THE CHARGING TIME BY PLACING A RESISTOR BETWEEN THE CAPACITOR AND THE 9-VOLT BATTERY:



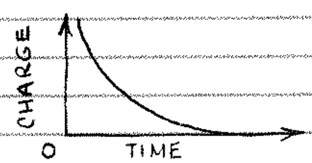
HERE'S A GRAPH OF THE CHARGING TIME:



□ DISCHARGING A CAPACITOR — THE ELECTRONS IN A CHARGED CAPACITOR WILL GRADUALLY LEAK THROUGH THE DIELECTRIC UNTIL BOTH PLATES HAVE AN EQUAL CHARGE. THE CAPACITOR IS THEN DISCHARGED. THE CAPACITOR CAN BE DISCHARGED VERY QUICKLY BY CONNECTING ITS PLATES TOGETHER. OR IT CAN BE DISCHARGED MORE SLOWLY BY CONNECTING A RESISTOR ACROSS IT:



HERE'S A GRAPH OF THE DISCHARGE TIME:

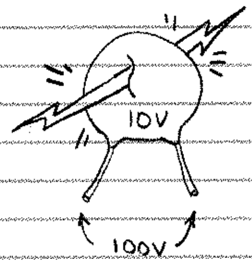


□ SPECIFYING CAPACITORS — THE ABILITY TO STORE ELECTRONS IS KNOWN AS CAPACITANCE. CAPACITANCE IS SPECIFIED IN FARADS. A 1-FARAD CAPACITOR CONNECTED TO A 1-VOLT SUPPLY WILL STORE 6,280,000,000,000,000,000 (6.28×10^{18}) ELECTRONS! MOST CAPACITORS HAVE MUCH SMALLER VALUES. SMALL CAPACITORS ARE SPECIFIED IN PICOFARADS (TRILLIONITHS OF A FARAD) AND LARGER CAPACITORS ARE SPECIFIED IN MICROFARADS (MILLIONTHS OF A FARAD). SUMMING UP:

1-FARAD = 1 F
1-MICROFARAD = $1\,\mu F = 10^{-6} F = 0.000\,001\,F$
1-PICOFARAD = $1\,pF = 10^{-12} F = 0.000\,000\,000\,001\,F$

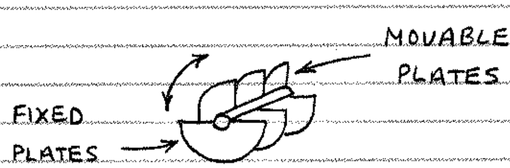
□ SUBSTITUTING CAPACITORS — THE CAPACITANCE SPECIFIED FOR MOST CAPACITORS MAY BE FROM 5 TO 100 % AWAY FROM THE ACTUAL VALUE. THEREFORE YOU CAN OFTEN SUBSTITUTE CLOSE VALUES FOR A SPECIFIED VALUE. BE SURE, HOWEVER, TO USE A CAPACITOR RATED AT THE EXPECTED MAXIMUM VOLTAGE LEVEL!

☐ CAPACITOR SUBSTITUTION PRECAUTIONS — YOU MUST MAKE SURE THE CAPACITOR YOU PLAN TO USE MEETS OR EXCEEDS THE REQUIRED VOLTAGE RATING. OTHERWISE ITS DIELECTRIC MAY BE ZAPPED BY THE STORED CHARGE. THE VOLTAGE RATING IS USUALLY PRINTED ON THE CAPACITOR. V MEANS VOLTS. WV IS WORKING VOLTS (SAME THING).

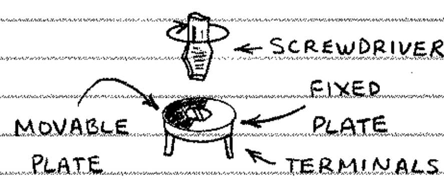


☐ KINDS OF CAPACITORS — CAPACITORS ARE OFTEN LABELED ACCORDING TO THEIR DIELECTRIC. THUS YOU'LL SEE REFERENCES TO CERAMIC, MICA, POLYSTYRENE AND MANY OTHERS. ALL THESE ARE FIXED VALUE CAPACITORS. SOME CAPACITORS HAVE A VARIABLE CAPACITY AND A SPECIAL CLASS OF FIXED CAPACITORS HAS MUCH MORE CAPACITY THAN OTHER CAPACITORS. HERE'S MORE:

VARIABLE CAPACITORS. THESE USUALLY HAVE ONE OR MORE NON-MOVING PLATES AND ONE OR MORE MOVING PLATES. THE CAPACITANCE IS CHANGED BY ROTATING A ROD AFFIXED TO ONE SIDE OF THE MOVABLE PLATES.

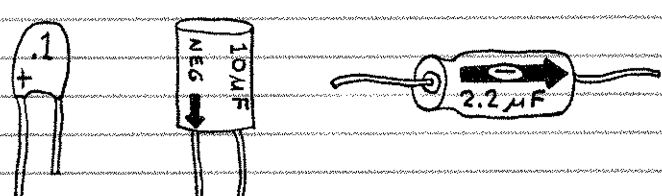


THIS KIND IS USED TO TUNE RADIO RECEIVERS AND TRANSMITTERS. THE DIELECTRIC IS USUALLY AIR.



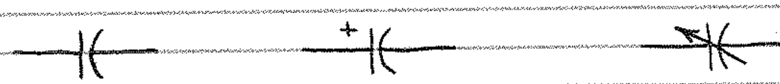
THIS KIND IS USED TO TUNE OSCILLATORS LIKE THOSE USED IN DIGITAL WATCHES. THEY'RE SMALL.

ELECTROLYTIC CAPACITORS. UNIQUE IN THAT A THIN OXIDE LAYER FORMED ON ALUMINUM OR TANTALUM FOIL IS THE DIELECTRIC. MUCH HIGHER CAPACITANCE THAN NON-ELECTROLYTIC TYPES. TANTALUM UNITS HAVE MORE CAPACITANCE PER VOLUME AND A LONGER LIFE THAN ALUMINUM ELECTROLYTICS. BUT THEY COST MORE. MOST ELECTROLYTICS ARE POLARIZED. THEY MUST BE CONNECTED INTO A CIRCUIT IN THE PROPER DIRECTION:



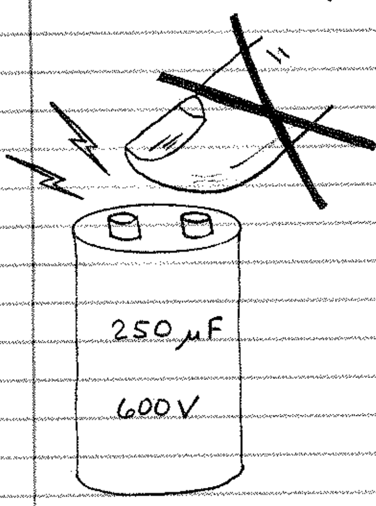
POSITIVE LEAD MUST GO TO MOST POSITIVE CONNECTION POINT!

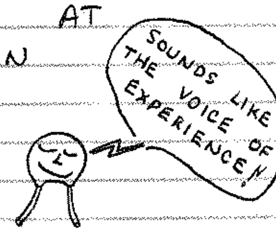
☐ CAPACITOR SYMBOLS:



FIXED FIXED VARIABLE

☐ WARNING! CAPACITORS CAN STORE A CHARGE FOR A CONSIDERABLE TIME AFTER THE POWER TO THEM HAS BEEN SWITCHED OFF. THIS CHARGE CAN BE DANGEROUS! A LARGE ELECTROLYTIC CHARGED TO ONLY 5 OR 10 VOLTS CAN MELT THE TIP OF A SCREWDRIVER PLACED ACROSS ITS TERMINALS! HIGH VOLTAGE CAPACITORS LIKE THOSE USED IN TELEVISION SETS AND PHOTOFLASH UNITS CAN STORE A LETHAL CHARGE! NEVER TOUCH THE LEADS OF SUCH A CAPACITOR. AT THE VERY LEAST THE JOLT CAN THROW YOU ACROSS A ROOM!

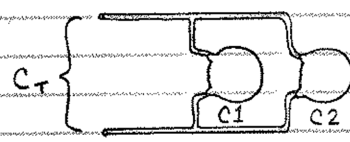




HOW CAPACITORS ARE USED

☐ PARALLEL CIRCUIT — OFTEN CAPACITORS ARE CONNECTED IN PARALLEL LIKE THIS:

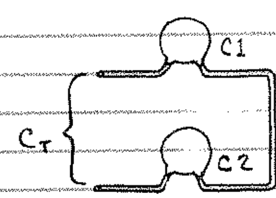
THE TOTAL CAPACITANCE IS THE SUM OF THE INDIVIDUAL CAPACITANCES.



$$C_T = C1 + C2$$

☐ SERIES CIRCUIT — SOMETIMES CAPACITORS ARE CONNECTED IN SERIES LIKE THIS:

THE TOTAL CAPACITANCE IS THE PRODUCT OF THE TWO CAPACITANCES DIVIDED BY THEIR SUM.



$$C_T = \frac{C1 \times C2}{C1 + C2}$$

THREE OR MORE CAPACITORS IN SERIES? HERE'S THE FORMULA:

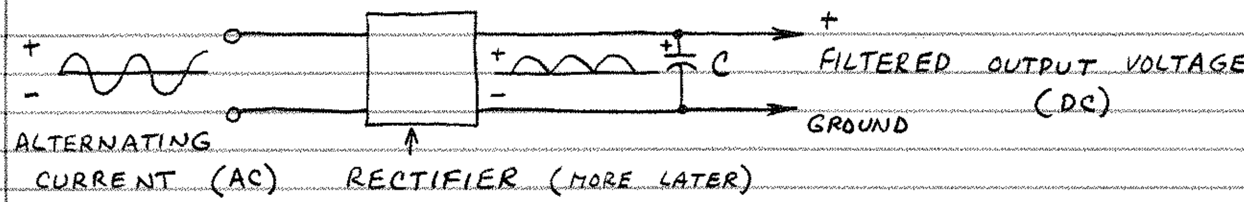
$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} \ldots \text{ETC.}}$$

☐ AND MORE — THERE ARE MANY OTHER WAYS TO USE CAPACITORS, SOME OF WHICH ARE SHOWN NEXT . . .

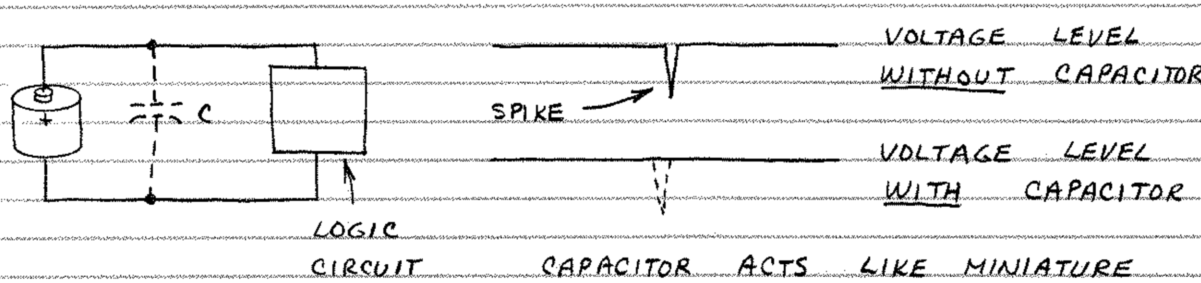
RESISTOR AND CAPACITOR APPLICATIONS

RESISTORS AND CAPACITORS ARE THE KEY INGREDIENTS OF MANY ELECTRONIC CIRCUITS. HERE ARE SOME REASONS WHY:

☐ POWER SUPPLY FILTER — A CAPACITOR WILL SMOOTH (FILTER) THE PULSATING VOLTAGE FROM A POWER SUPPLY INTO A STEADY DIRECT CURRENT (DC).



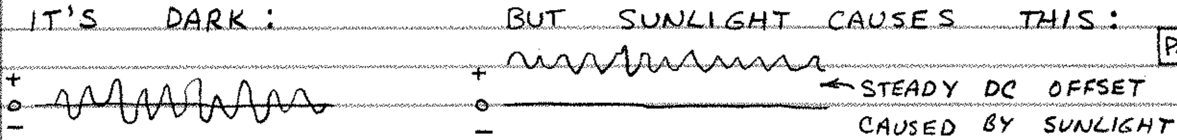
☐ SPIKE REMOVER — DIGITAL LOGIC CIRCUITS, WHICH WE'LL FIND OUT MORE ABOUT LATER, CAN USE LOTS OF CURRENT MOMENTARILY WHEN THEY SWITCH FROM OFF TO ON OR VICE VERSA. THIS CAN CAUSE VERY BRIEF BUT SUBSTANTIAL REDUCTIONS IN POWER APPLIED TO NEARBY CIRCUITS. THESE POWER SPIKES (OR GLITCHES, AS THEY ARE SOMETIMES CALLED) CAN BE ELIMINATED BY PLACING A SMALL (0.1 μF) CAPACITOR ACROSS THE POWER LEADS OF THE LOGIC CIRCUIT:



CAPACITOR ACTS LIKE MINIATURE BATTERY THAT SUPPLIES POWER DURING THE SPIKE.

☐ AC-DC SELECTIVE FILTER — OFTEN AN ELECTRICAL SIGNAL WILL BE RIDING ATOP A STEADY DC SIGNAL. FOR EXAMPLE, THE SIGNAL FROM A LIGHTWAVE COMMUNICATION SYSTEM MAY LOOK LIKE THIS WHEN IT'S DARK: BUT SUNLIGHT CAUSES THIS:

P. 123

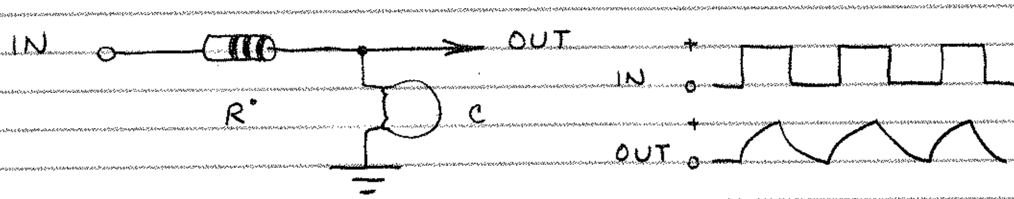


A CAPACITOR WILL PASS THE FLUCTUATING SIGNAL AND COMPLETELY BLOCK THE STEADY DC LEVEL.

☐ R-C CIRCUITS — TWO CIRCUITS THAT COMBINE A RESISTOR (R) AND CAPACITOR (C) ARE VERY IMPORTANT. THEY ARE THE INTEGRATOR AND DIFFERENTIATOR. BOTH THESE CIRCUITS ARE USED TO RESHAPE AN INCOMING STREAM OF WAVES OR PULSES.

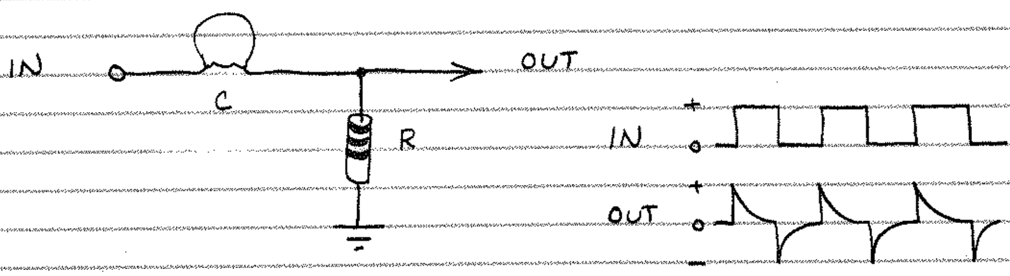
THE PRODUCT OF R AND C IN THESE CIRCUITS IS CALLED THE RC TIME CONSTANT. FOR THE CIRCUITS SHOWN BELOW, THE RC TIME CONSTANT (IN SECONDS) IS AT LEAST TEN TIMES THE INTERVAL BETWEEN INCOMING CYCLES OR PULSES.

1. INTEGRATOR. HERE'S A BASIC RC INTEGRATOR:



IF THE INPUT PULSES ARE SPEEDED UP, THE OUTPUT WAVEFORMS (OFTEN CALLED A SAWTOOTH) WILL NOT REACH THEIR FULL HEIGHT (AMPLITUDE). IT'S EASY TO DESIGN AN AMPLIFIER THAT IGNORES WAVES WITH LESS THAN A DESIRED AMPLITUDE. THEREFORE, THE INTEGRATOR CAN FUNCTION AS A FILTER WHICH PASSES ONLY SIGNALS BELOW A CERTAIN FREQUENCY.

2. DIFFERENTIATOR. HERE'S A BASIC RC DIFFERENTIATOR:



THIS CIRCUIT PRODUCES SYMMETRICAL OUTPUT WAVES WITH SHARP POSITIVE AND NEGATIVE PEAKS. IT'S USED TO MAKE NARROW PULSE GENERATORS FOR TELEVISION RECEIVERS AND TO TRIGGER DIGITAL LOGIC CIRCUITS.

☐ MORE ABOUT R-C — YOU WILL OFTEN SEE REFERENCES TO THE RC TIME CONSTANT OF A CIRCUIT. IT'S THE TIME IN SECONDS FOR A CHARGING OR DISCHARGING CAPACITOR TO GO THROUGH 63.3% OF THE CHANGE IN CHARGE.

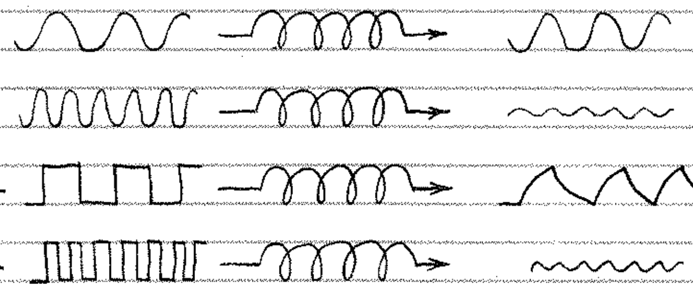
COILS

ELECTRONS MOVING THROUGH A WIRE CAUSE AN ELECTROMAGNETIC FIELD TO ENCIRCLE THE WIRE. AS YOU KNOW FROM CHAPTER 1, PASSING A CURRENT THROUGH A WIRE THAT'S BEEN WRAPPED AS A COIL (P. 15) CREATES AN EVEN STRONGER FIELD. THIS FIELD MAKES POSSIBLE SOLENOIDS, MOTORS AND ELECTROMAGNETS. COILS HAVE OTHER IMPORTANT ROLES, TOO:

1. COILS RESIST RAPID CHANGES IN THE CURRENT FLOWING THROUGH THEM WHILE FREELY PASSING STEADY (DC) CURRENT. HERE ARE SOME EXAMPLES:

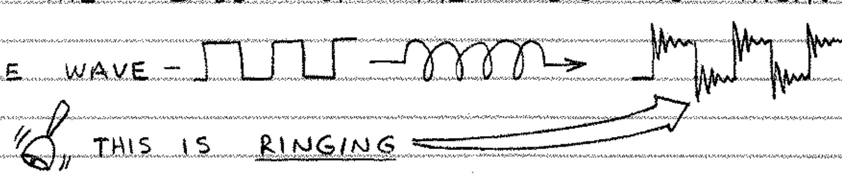
SIGNAL — IN — COIL — OUT

SLOW SINE WAVE –
FAST SINE WAVE –
SLOW SQUARE WAVE –
FAST SQUARE WAVE –

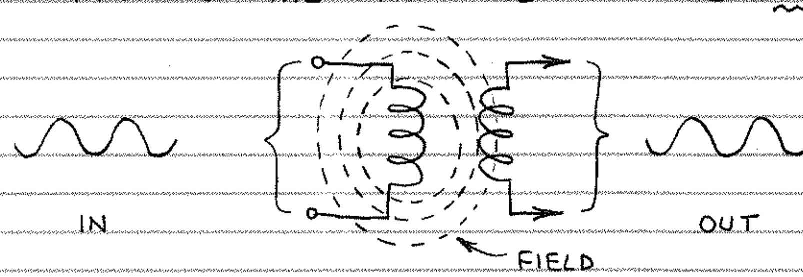


SOMETIMES A COIL WILL ADD RINGING TO A SQUARE WAVE PASSING THROUGH IT. THIS CAN HAPPEN WHEN THE RESISTANCE OF THE EXTERNAL CURRENT PATH THAT CONNECTS THE ENDS OF THE COIL IS HIGH.

SQUARE WAVE –



2. SOME OF THE ENERGY IN THE FIELD AROUND A COIL CAN BE INDUCED (TRANSFERRED) INTO A SECOND, NEARBY COIL. THIS IS THE PRINCIPLE OF THE TRANSFORMER:

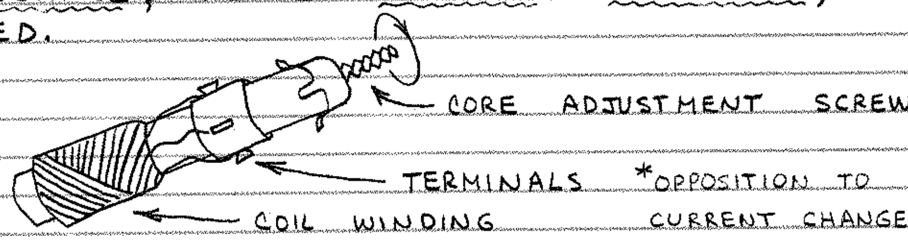


THE INPUT SIDE OF THE TRANSFORMER IS CALLED THE PRIMARY. THE OUTPUT SIDE IS CALLED THE SECONDARY.

☐ TYPES OF COILS — THERE ARE MANY DIFFERENT TYPES OF COILS. HERE ARE SOME OF THEM:

TUNING COIL. RADIOS USE VARIOUS COILS TO HELP SELECT A DESIRED SIGNAL. TUNING COILS HAVE A SERIES OF TAPS OR A MOVABLE CORE SO THEIR INDUCTANCE*, HENCE RESONANT FREQUENCY, CAN BE CHANGED.

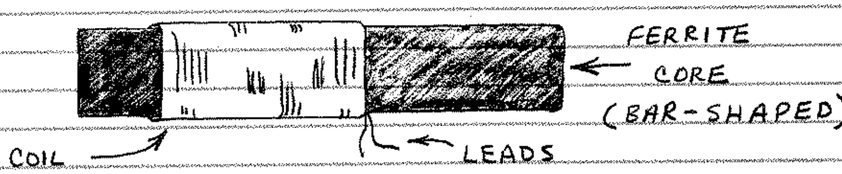
TYPICAL TUNING COIL



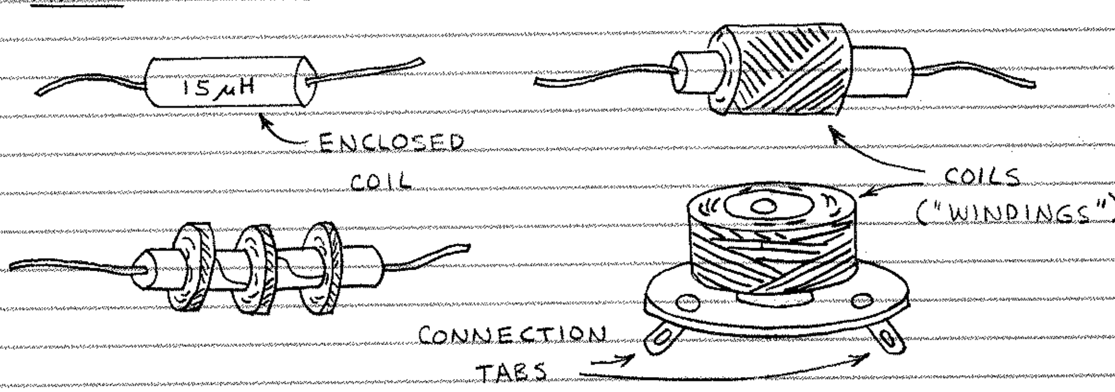
*OPPOSITION TO CURRENT CHANGES.

ANTENNA COIL. RADIOS OFTEN USE A BROADLY TUNED COIL TO PICK UP RADIO SIGNALS.

TYPICAL ANTENNA COIL



CHOKE. USED IN MANY CIRCUITS TO LIMIT OR SUPPRESS FLUCTUATING SIGNALS WHILE PASSING A STEADY CURRENT. CHOKES ARE AVAILABLE IN MANY SHAPES AND SIZES:



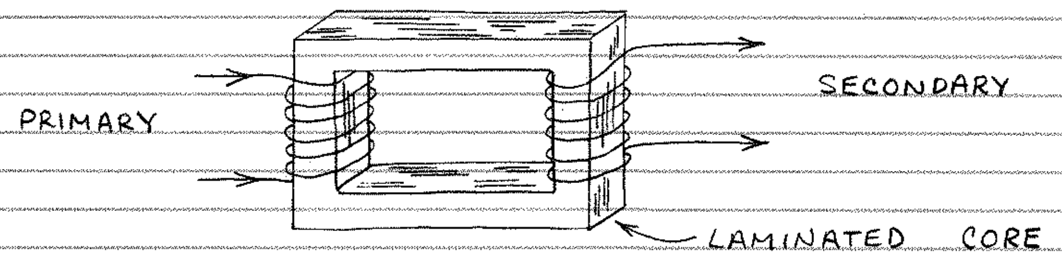
TRANSFORMER. SO IMPORTANT WE'LL DEVOTE A COMPLETE SECTION TO IT.

☐ APPLICATIONS FOR COILS — IN ADDITION TO THOSE ALREADY DESCRIBED, COILS ARE USED IN FILTERS THAT SELECTIVELY PASS SPECIFIC FREQUENCY BANDS.

☐ CAUTION! A HIGH VOLTAGE PULSE CAN BE PRODUCED IN A CHOKE WHEN THE CURRENT FLOWING THROUGH IT IS INTERRUPTED. BE CAREFUL.

TRANSFORMERS

TRANSFORMERS ARE A MAJOR CLASS OF COILS HAVING TWO OR MORE WINDINGS USUALLY WRAPPED AROUND A COMMON CORE MADE FROM LAMINATED IRON SHEETS. HERE'S A SIMPLE TRANSFORMER:



IF THE CURRENT FLOWING THROUGH THE PRIMARY COIL IS FLUCTUATING, THEN A CURRENT WILL BE INDUCED INTO THE SECONDARY WINDING. A STEADY (DC) CURRENT WILL NOT BE TRANSFERRED FROM ONE COIL TO THE OTHER.

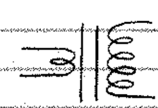
☐ HOW THEY WORK — TRANSFORMERS HAVE THE ABILITY TO TRANSFORM VOLTAGE AND CURRENT TO HIGHER OR LOWER LEVELS. THEY DO NOT, OF COURSE, CREATE POWER FROM NOTHING. THEREFORE, IF A TRANSFORMER BOOSTS THE VOLTAGE OF A SIGNAL, IT REDUCES ITS CURRENT. AND IF IT CUTS THE VOLTAGE OF A SIGNAL, IT RAISES ITS CURRENT. IN OTHER WORDS... THE POWER FLOWING FROM A TRANSFORMER CANNOT EXCEED THE INCOMING POWER!

☐ TURNS RATIO — THE RATIO OF PRIMARY TO SECONDARY TURNS DETERMINES A TRANSFORMER'S VOLTAGE RATIO...

1:1 RATIO.

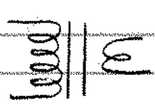
THE PRIMARY VOLTAGE AND CURRENT ARE TRANSFERRED UNALTERED TO THE SECONDARY. OFTEN CALLED AN ISOLATION TRANSFORMER.

STEP-UP.



THE VOLTAGE IS INCREASED BY THE TURNS RATIO. THUS A 1:5 TURNS RATIO WILL BOOST 5-VOLTS AT THE PRIMARY INTO 25-VOLTS AT THE SECONDARY.

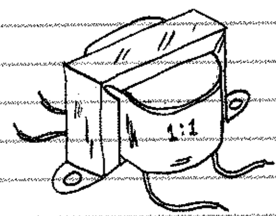
STEP-DOWN.



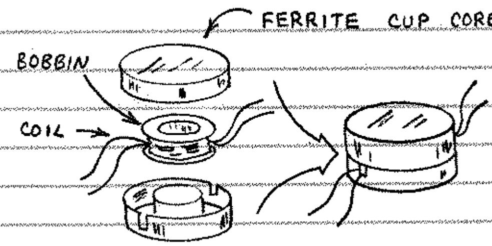
THE VOLTAGE IS REDUCED BY THE TURNS RATIO. THUS A 5:1 TURNS RATIO WILL DROP 25-VOLTS AT THE PRIMARY TO 5-VOLTS AT THE SECONDARY.

☐ TRANSFORMER TYPES AND APPLICATIONS — HERE ARE SOME OF THE MAJOR TRANSFORMER TYPES:

ISOLATION.



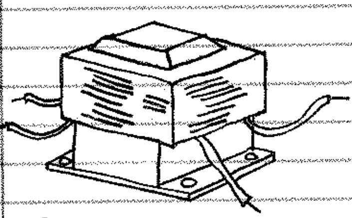
USED TO ISOLATE DIFFERENT PARTS OF A CIRCUIT AND TO PROVIDE PROTECTION FROM ELECTRICAL SHOCK.



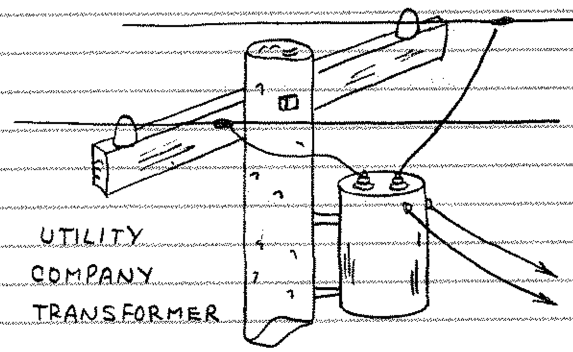
STANDARD 1:1 ISOLATION

MINIATURE 1:1 ISOLATION

POWER CONVERSION.



OFTEN USED TO REDUCE POWER LINE VOLTAGE TO USABLE LEVEL.



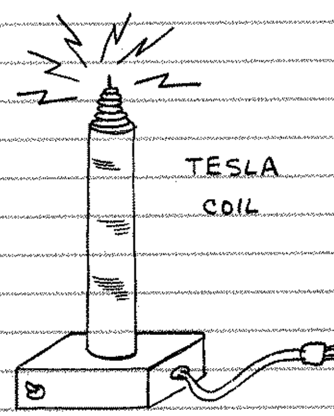
UTILITY COMPANY TRANSFORMER

POWER TRANSFORMER

HIGH-VOLTAGE.

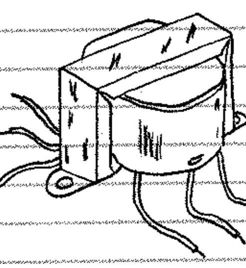
AUTOMOTIVE IGNITION COIL

USED TO PRODUCE IGNITION SPARKS IN GASOLINE ENGINES. ALSO USED TO POWER TV PICTURE TUBES, SOME LASERS, NEON LIGHTS, ETC.

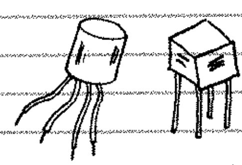


TESLA COIL

AUDIO.



USED TO MATCH THE IMPEDANCE* OF AN AMPLIFIER TO THAT OF A MICROPHONE, SPEAKER OR OTHER DEVICE.
*OPPOSITION TO THE FLOW OF ALTERNATING CURRENT.



MINIATURE

TAPPED PRIMARY AND SECONDARY WINDINGS

NOTE: LEADS OF TRANSFORMERS ARE COLOR CODED.

3. SEMICONDUCTORS

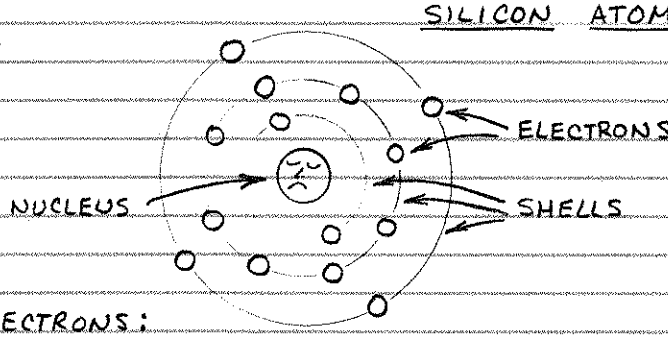
THE MOST EXCITING AND IMPORTANT ELECTRONIC COMPONENTS ARE MADE FROM CRYSTALS CALLED SEMICONDUCTORS. DEPENDING ON CERTAIN CONDITIONS, A SEMICONDUCTOR CAN ACT LIKE A CONDUCTOR OR AN INSULATOR.

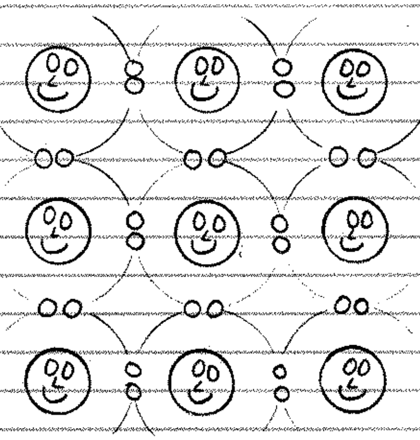
SILICON

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:

SILICON ATOM



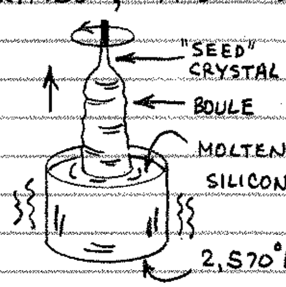


A CLUSTER OF SILICON ATOMS SHARING OUTER ELECTRONS FORMS A REGULAR ARRANGEMENT CALLED A CRYSTAL.

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

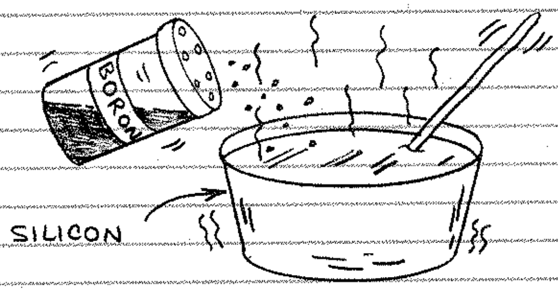
SILICON FORMS 27.7 % OF THE EARTH'S CRUST! ONLY OXYGEN IS MORE COMMON. IT'S NEVER FOUND IN THE PURE STATE. WHEN PURIFIED, IT'S DARK GRAY IN COLOR.

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



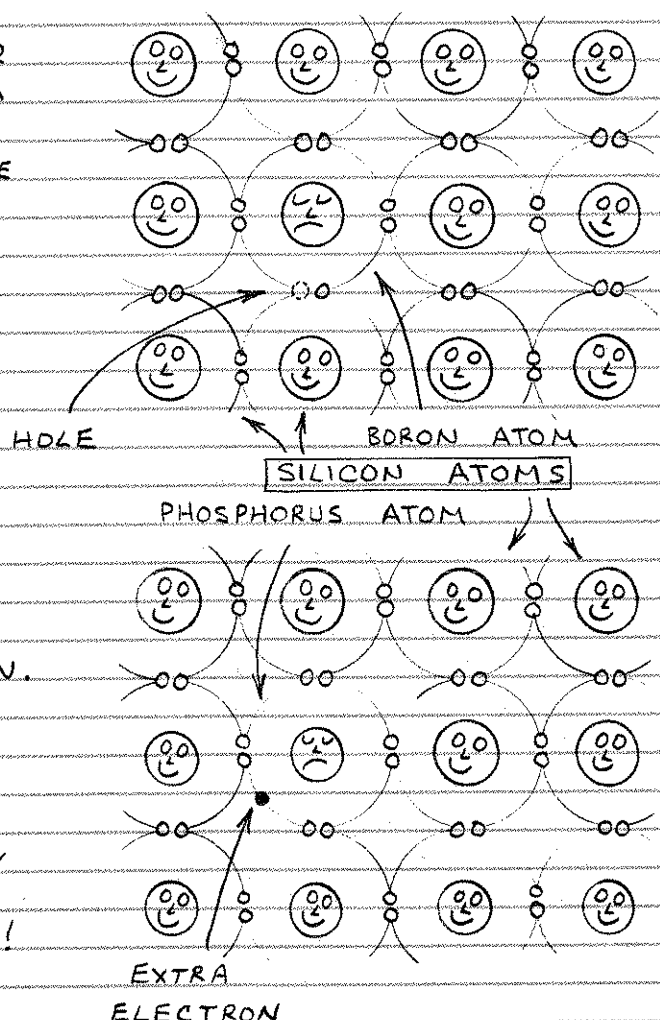
SILICON CAN BE GROWN INTO BIG CRYSTALS. IT'S CUT INTO WAFERS FOR MAKING ELECTRONIC PARTS.

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. HERS'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.

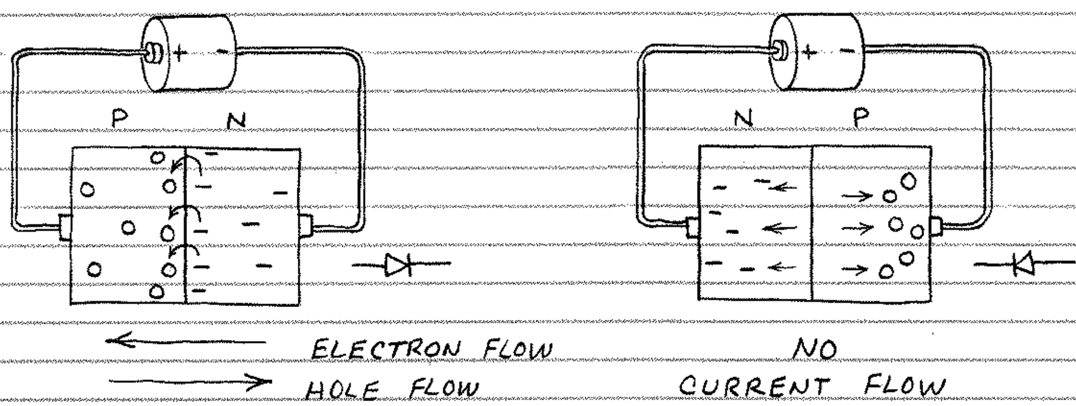
THE DIODE

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).

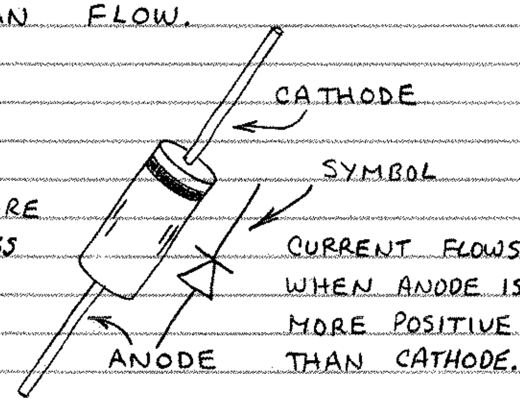
FORWARD BIAS | REVERSE BIAS



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.

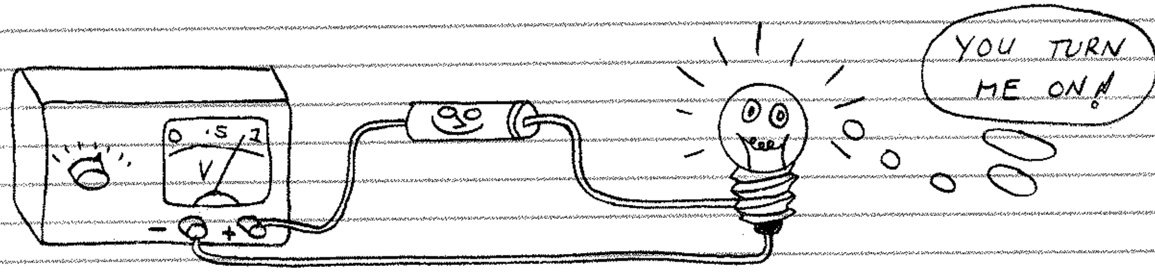
HERE THE CHARGE FROM THE BATTERY ATTRACTS HOLES AND ELECTRONS AWAY FROM THE JUNCTION. THEREFORE, NO CURRENT CAN FLOW.

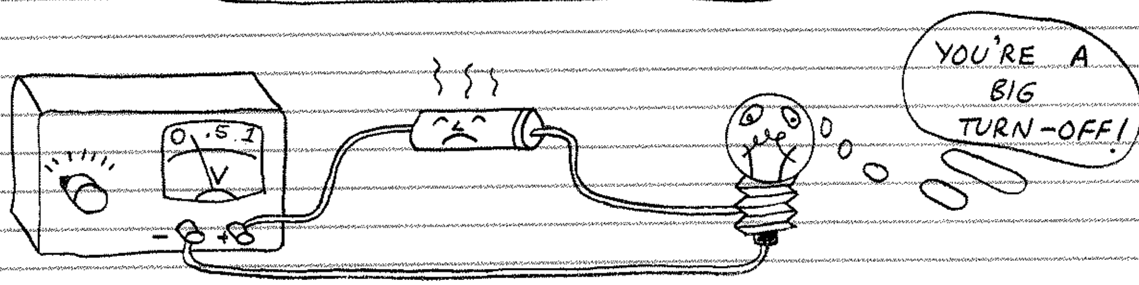
☐ A TYPICAL DIODE — DIODES ARE COMMONLY ENCLOSED IN SMALL GLASS CYLINDERS. A DARK BAND MARKS THE CATHODE TERMINAL. THE OPPOSITE TERMINAL IS THE ANODE



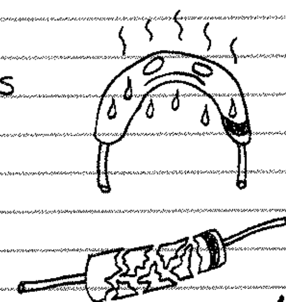
☐ DIODE OPERATION — YOU ALREADY KNOW A DIODE IS LIKE AN ELECTRONIC ONE-WAY VALVE. IT'S IMPORTANT TO UNDERSTAND SOME ADDITIONAL ASPECTS OF DIODE OPERATION. HERE ARE SOME KEY ONES:

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.

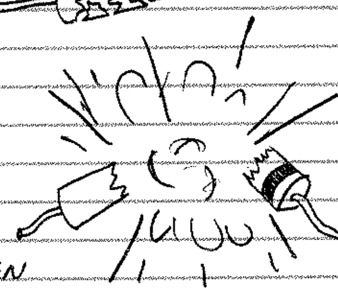




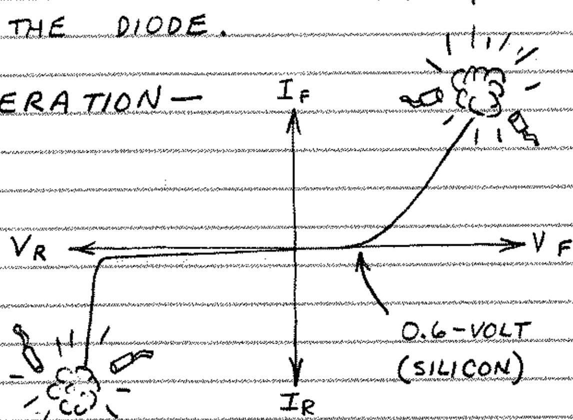
2. IF THE FORWARD CURRENT BECOMES EXCESSIVE, THE SEMICONDUCTOR CHIP MAY CRACK OR MELT! AND THE CONTACTS MAY SEPARATE. IF THE CHIP MELTS, THE DIODE MAY SUDDENLY CONDUCT IN BOTH DIRECTIONS. THE RESULTING HEAT MAY VAPORIZE THE CHIP!



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.



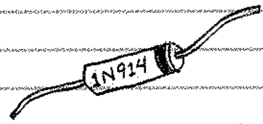
☐ SUMMING UP DIODE OPERATION — THIS GRAPH SUMS UP DIODE OPERATION. (IT'S APPROXIMATE.)



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

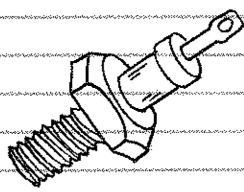
☐ TYPES OF DIODES — MANY DIFFERENT KINDS OF DIODES ARE AVAILABLE. HERE ARE SOME OF THE MAJOR TYPES:

SMALL SIGNAL.



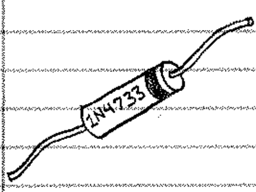
SMALL SIGNAL DIODES ARE USED TO TRANSFORM LOW CURRENT AC TO DC, DETECT (DEMODULATE) RADIO SIGNALS, MULTIPLY VOLTAGE, PERFORM LOGIC, ABSORB VOLTAGE SPIKES, ETC.

POWER RECTIFIER.



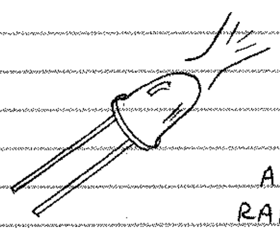
FUNCTIONALLY IDENTICAL TO SMALL SIGNAL DIODES, POWER RECTIFIERS CAN HANDLE MUCH MORE CURRENT. THEY ARE INSTALLED IN LARGE METAL PACKAGES THAT SOAK UP EXCESS HEAT AND TRANSFER IT TO A METAL HEAT SINK. USED MAINLY IN POWER SUPPLIES.

ZENER.



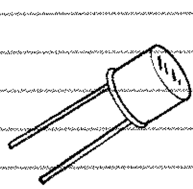
THE ZENER DIODE IS DESIGNED TO HAVE A SPECIFIC REVERSE BREAKDOWN (CONDUCTION) VOLTAGE. THIS MEANS ZENER DIODES CAN FUNCTION LIKE A VOLTAGE SENSITIVE SWITCH. ZENER DIODES HAVING BREAKDOWN VOLTAGES (V_Z) OF FROM ABOUT 2-VOLTS TO 200-VOLTS ARE AVAILABLE.

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.

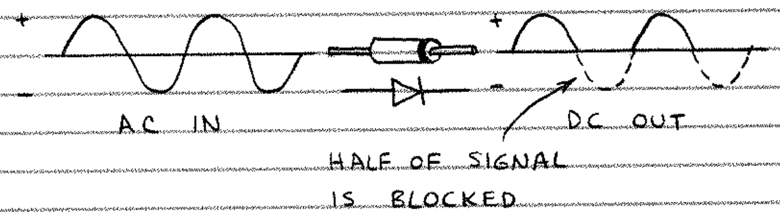


ALL DIODES RESPOND TO SOME DEGREE WHEN ILLUMINATED BY LIGHT. DIODES DESIGNED SPECIFICALLY TO DETECT LIGHT ARE CALLED PHOTODIODES. THEY INCLUDE A GLASS OR PLASTIC WINDOW THROUGH WHICH THE LIGHT ENTERS. OFTEN THEY HAVE A LARGE, EXPOSED JUNCTION REGION. SILICON MAKES GOOD PHOTODIODES.

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

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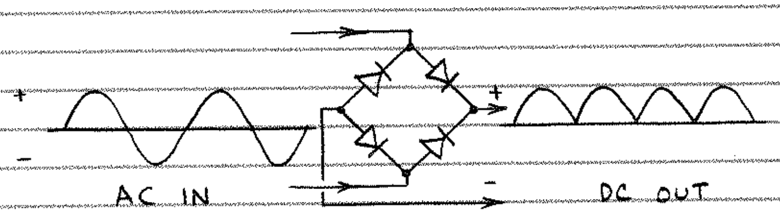


THIS 4-DIODE "NETWORK" (OR BRIDGE RECTIFIER) RECTIFIES BOTH HALVES OF AN AC SIGNAL.

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:

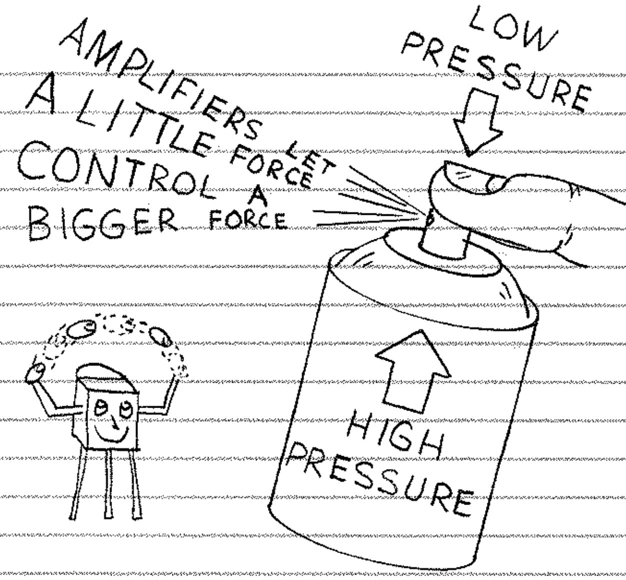
1. BEGINNING WITH BENJAMIN FRANKLIN, IT WAS TRADITIONALLY ASSUMED ELECTRICITY FLOWS FROM A POSITIVELY CHARGED TO A NEGATIVELY CHARGED REGION. THE DISCOVERY OF THE ELECTRON CORRECTED THAT. (BUT MOST ELECTRICAL CIRCUIT DIAGRAMS TODAY STILL FOLLOW THE OLD TRADITION IN WHICH THE POSITIVE POWER SUPPLY CONNECTION 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.

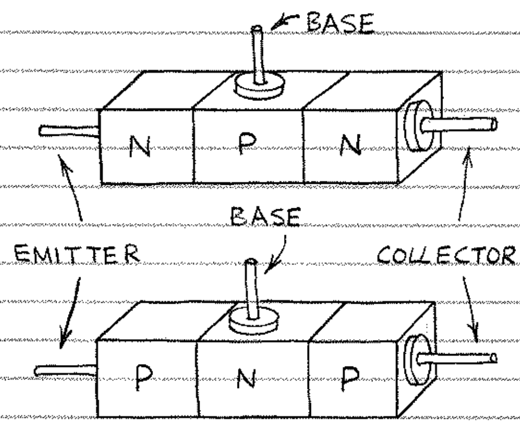
THE TRANSISTOR

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.

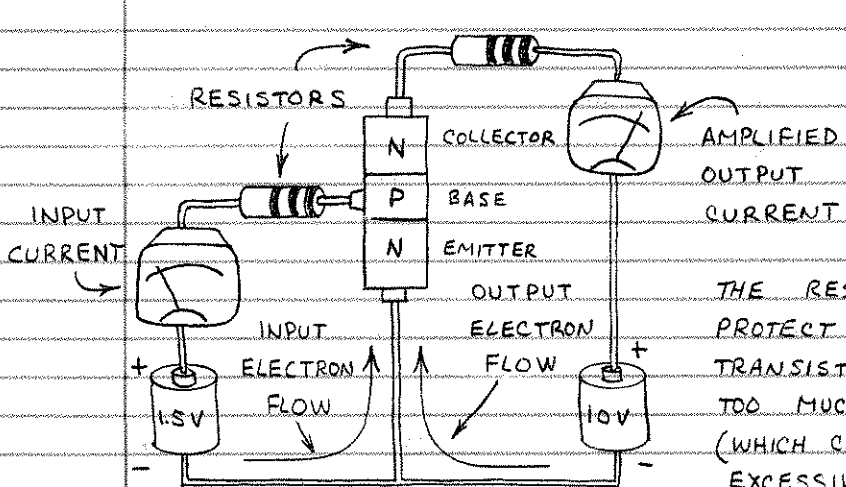


BIPOLAR TRANSISTORS

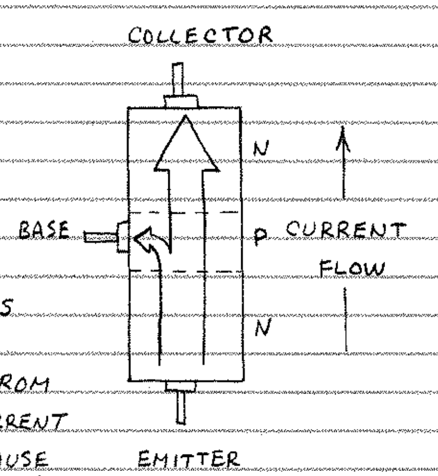
ADD A SECOND JUNCTION TO A PN JUNCTION DIODE AND YOU GET A 3-LAYER SILICON SANDWICH. THE SANDWICH CAN BE EITHER NPN OR PNP. EITHER WAY, THE MIDDLE LAYER ACTS LIKE A FAUCET OR GATE THAT CONTROLS THE CURRENT MOVING THROUGH THE THREE LAYERS.



☐ 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).

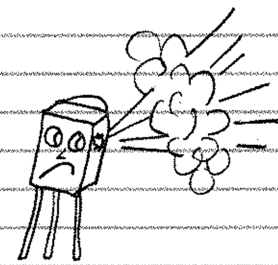


☐ MORE ABOUT BIPOLAR TRANSISTOR OPERATION — DIODES AND TRANSISTORS SHARE SEVERAL KEY FEATURES:

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

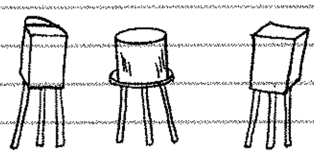
2. TOO MUCH CURRENT WILL CAUSE A TRANSISTOR TO BECOME HOT AND OPERATE IMPROPERLY. IF A TRANSISTOR IS HOT WHEN TOUCHED, DISCONNECT THE POWER TO IT!

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!



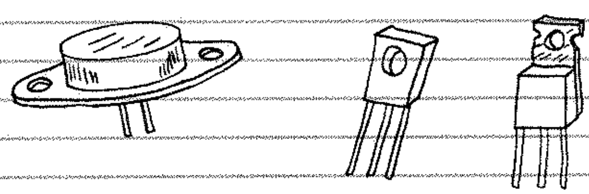
☐ KINDS OF TRANSISTORS — MANY DIFFERENT KINDS OF TRANSISTORS ARE AVAILABLE. HERE ARE EXAMPLES OF THE MOST IMPORTANT:

SMALL SIGNAL AND SWITCHING.



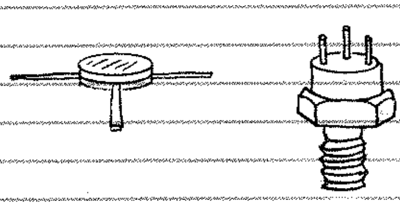
SMALL SIGNAL TRANSISTORS ARE USED TO AMPLIFY LOW LEVEL SIGNALS. SWITCHING TRANSISTORS ARE DESIGNED TO BE OPERATED FULLY ON OR OFF. SOME TRANSISTORS CAN BOTH AMPLIFY AND SWITCH EQUALLY WELL.

POWER.



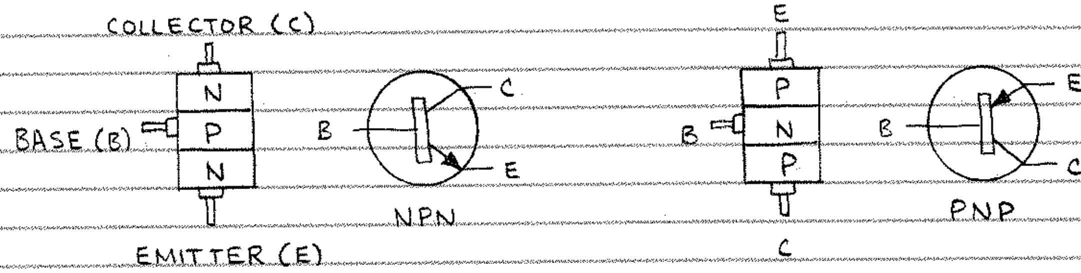
POWER TRANSISTORS ARE USED IN HIGH POWER AMPLIFIERS AND POWER SUPPLIES. LARGE SIZE AND EXPOSED METAL SURFACES KEEP THEM COOL.

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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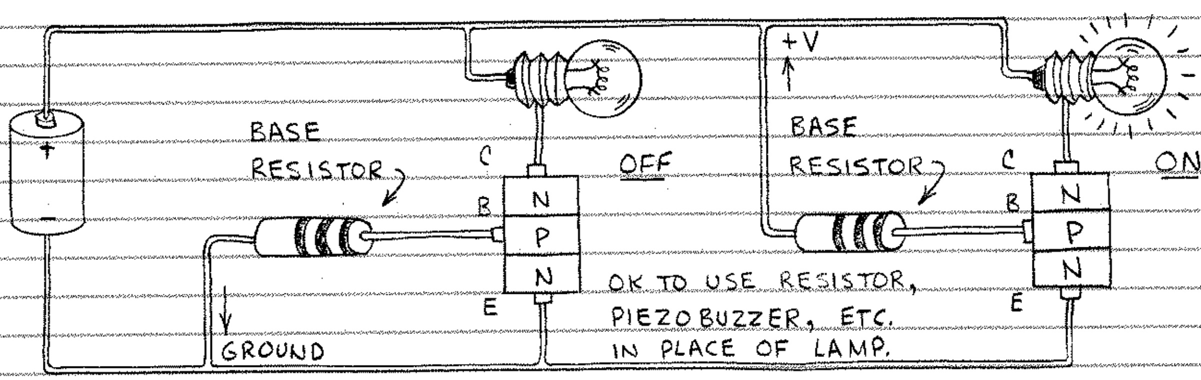

ONLY TWO INPUTS ARE POSSIBLE: GROUND (0 VOLTS) AND THE POSITIVE BATTERY VOLTAGE (+V). THEREFORE THE TRANSISTOR IS OFF OR ON. A TYPICAL BASE RESISTANCE IS 5,000 TO 10,000 OHMS. (IF THE RESISTOR IS REPLACED BY A WIRE, THE LAMP CAN BE SWITCHED ON OR OFF FROM A CONSIDERABLE DISTANCE.)