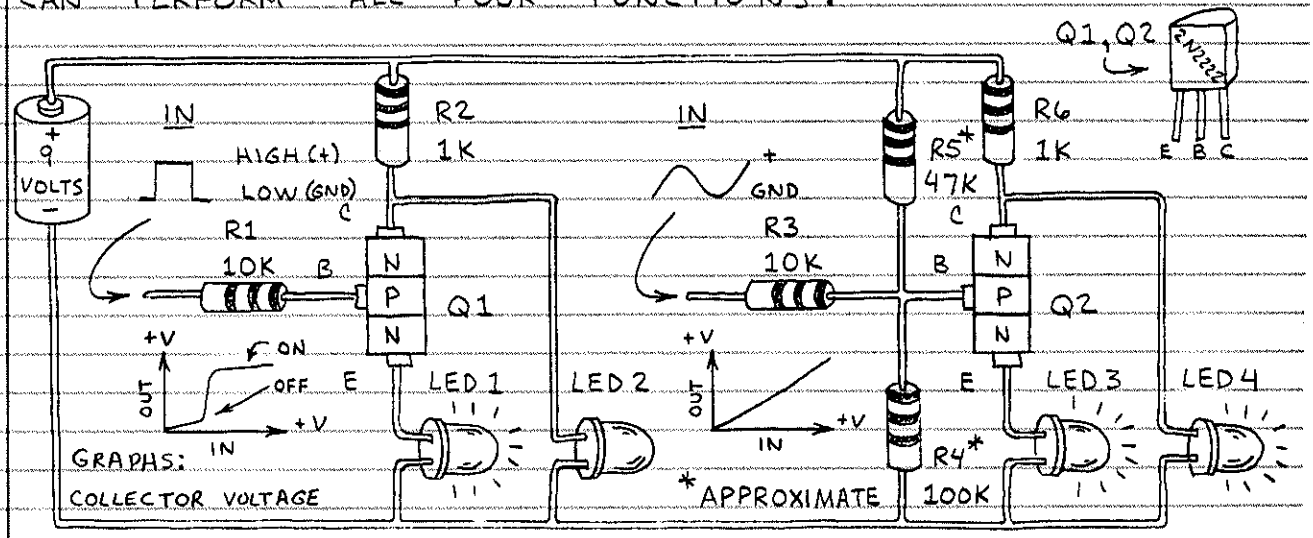
7. LINEAR INTEGRATED CIRCUITS

THE INPUT AND OUTPUT VOLTAGE LEVELS OF LINEAR INTEGRATED CIRCUITS CAN VARY OVER A WIDE RANGE. OFTEN THE OUTPUT VOLTAGE IS PROPORTIONAL TO THE INPUT VOLTAGE. THEREFORE, A GRAPH OF INPUT VERSUS OUTPUT IS A STRAIGHT (LINEAR) LINE. THERE ARE MANY TYPES OF LINEAR IC's. ONLY THE MAJOR TYPES ARE COVERED HERE. FIRST LET'S COMPARE THE BASIC DIGITAL AND LINEAR CIRCUITS:

THE BASIC LINEAR CIRCUIT

A SINGLE BIPOLAR OR FIELD-EFFECT TRANSISTOR CAN FUNCTION AS A DIGITAL OR LINEAR CIRCUIT. IN BOTH CASES, THE TRANSISTOR CAN INVERT THE SIGNAL AT ITS INPUT. HERE'S HOW AN NPN BIPOLAR TRANSISTOR CAN PERFORM ALL FOUR FUNCTIONS:



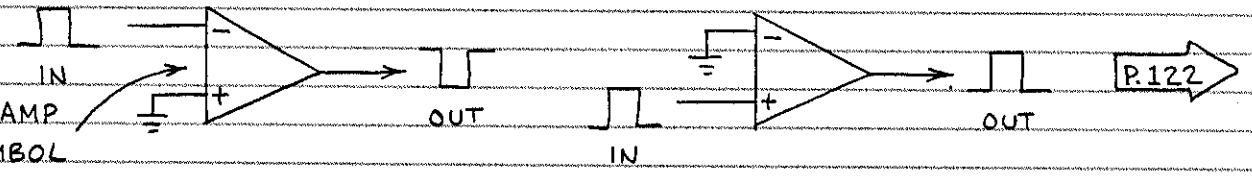
HERE TRANSISTOR Q1 IS USED AS A SWITCH. WHEN THE INPUT IS NEAR +V (OR HIGH), Q1 TURNS ON AND LED 1 IS ILLUMINATED. WHEN THE INPUT IS NEAR GROUND (OR LOW), Q1 TURNS OFF. THIS TURNS LED 1 OFF AND ALLOWS LED 2 TO GLOW. (R2 CONTROLS THE CURRENT THROUGH BOTH LEDs.) THIS CIRCUIT IS THEN A COMBINED DIGITAL BUFFER AND INVERTER.

HERE Q2 IS AN AMPLIFIER THAT OPERATES OVER THE ENTIRE RANGE FROM FULL OFF TO FULL ON. R4 AND R5 FORM A VOLTAGE DIVIDER THAT APPLIES A SMALL VOLTAGE TO Q2's BASE TO KEEP Q2 SLIGHTLY ON EVEN WHEN NO INPUT IS PRESENT. THIS ALLOWS Q2 TO OPERATE IN A LINEAR MODE. AS THE INPUT VOLTAGE RISES, LED 3 BRIGHTENS AND LED 4 DIMS.

OPERATIONAL AMPLIFIERS

OPERATIONAL AMPLIFIERS (OR "OP-AMPS") ARE BY FAR THE MOST VERSATILE OF LINEAR I.C.'s. THEY'RE CALLED "OPERATIONAL" AMPLIFIERS SINCE THEY WERE ORIGINALLY DESIGNED TO DO MATHEMATICAL OPERATIONS. OP-AMPS AMPLIFY THE DIFFERENCE BETWEEN VOLTAGES OR SIGNALS (AC OR D.C) APPLIED TO THEIR TWO INPUTS. THE VOLTAGE APPLIED TO ONLY ONE INPUT WILL BE AMPLIFIED IF THE SECOND INPUT IS GROUNDED OR MAINTAINED AT SOME VOLTAGE LEVEL.

☐ OP-AMP OPERATION — THE OP-AMP HAS AN INVERTING AND NON-INVERTING INPUT. THE POLARITY OF A VOLTAGE APPLIED TO THE INVERTING INPUT IS REVERSED AT THE OUTPUT. (INVERTING INPUT IS − ; NON-INVERTING INPUT IS +.)



INVERTING MODE NON-INVERTING MODE

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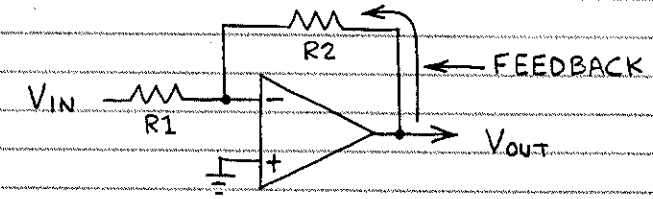
☐ OP-AMP "FEEDBACK" — THE CIRCUITS SHOWN ABOVE ALLOW THE OP-AMP TO OPERATE AT ITS MAXIMUM AMPLIFICATION LEVEL (OR GAIN). USUALLY THE GAIN IS REDUCED TO A MORE PRACTICAL LEVEL BY FEEDING SOME OF THE OUTPUT BACK TO THE INVERTING (−) INPUT. FOR EXAMPLE:



INVERTING AMPLIFIER

GAIN = R2 / R1

$V_{OUT} = -V_{IN}(R2/R1)$

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☐ OP-AMP COMPARATOR — WHEN OPERATED WITHOUT A FEEDBACK RESISTOR (R2 ABOVE), THE OUTPUT VOLTAGE WILL SWING FROM FULL ON TO FULL OFF (OR VICE VERSA) WHEN THE VOLTAGES APPLIED TO THE INPUTS DIFFER BY ONLY ABOUT 0.001 VOLT! THIS DIGITAL-LIKE MODE MAKES POSSIBLE MANY USEFUL APPLICATIONS.

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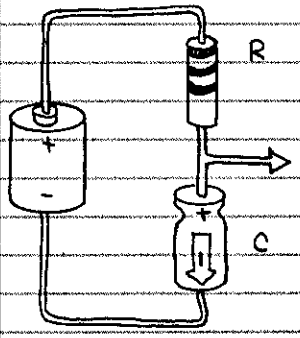
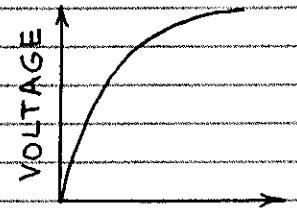
☐ TYPES OF OP-AMPS — BOTH BIPOLAR AND MOSFET I.C OP-AMPS ARE AVAILABLE. SOME BIPOLAR OP-AMPS HAVE FET OR MOSFET INPUTS TO PROVIDE VERY HIGH INPUT RESISTANCE. MANY DIFFERENT OP-AMPS ARE MADE. A SINGLE I.C MAY INCLUDE UP TO FOUR INDIVIDUAL OP-AMPS.

TIMERS

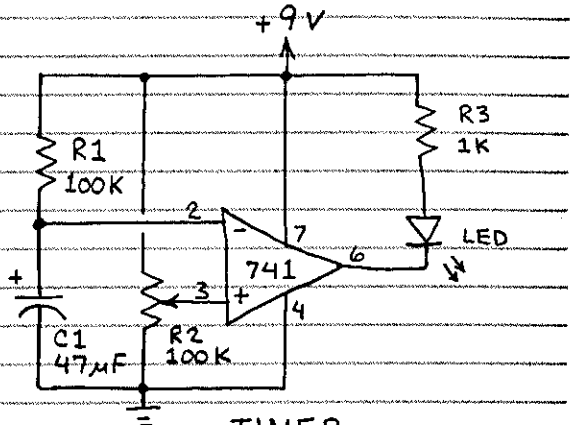
WHEN OPERATED AS A COMPARATOR, THE OP-AMP CAN BE USED AS A TIMER. ALL THAT'S REQUIRED IS AN RC (RESISTOR-CAPACITOR) CIRCUIT LIKE THIS:



RC CIRCUIT



RC CHARGING GRAPH



TIMER

IN THE CIRCUIT DIAGRAM (ABOVE RIGHT), R1 AND C1 FORM AN RC CIRCUIT. C1 GRADUALLY CHARGES TO +9 VOLTS THROUGH R1. WHEN THE VOLTAGE ON C1 EXCEEDS THE REFERENCE VOLTAGE SUPPLIED TO THE NON-INVERTING INPUT OF THE OP-AMP, ITS OUTPUT SWINGS FROM HIGH TO LOW AND THE LED GLOWS. THE TIME DELAY CAN BE CHANGED BY ALTERING THE VALUES OF R1 AND C1 OR THE SETTING OF R2. DISCHARGE C1 (USE PUSHBUTTON SWITCH) FOR NEW CYCLE.

☐ IC TIMERS — THE SIMPLE CIRCUIT ABOVE IS THE KEY INGREDIENT OF MOST IC TIMERS. MOST INCLUDE AN OUTPUT FLIP-FLOP TO GIVE DEFINITE HIGH OR LOW OUTPUT. SOME INCLUDE A BINARY COUNTER THAT ADVANCES ONE COUNT PER DELAY PERIOD (OR CYCLE). THE TIMER IS RECYCLED EACH TIME THE COUNT ADVANCES. A DECODER AT THE COUNTER OUTPUT ALLOWS TOTAL DELAYS OF FROM DAYS TO A YEAR OR MORE TO BE SELECTED. BOTH BIPOLAR AND CMOS TIMERS ARE AVAILABLE.

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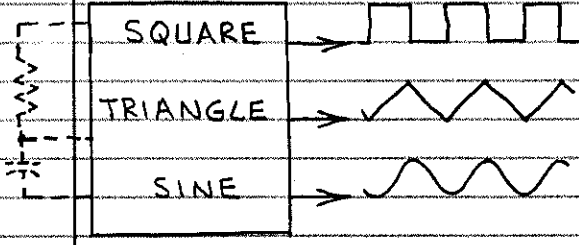
FAMOUS FACT: ANALOG COMPUTERS USE OP-AMPS TO SOLVE COMPLEX EQUATIONS!

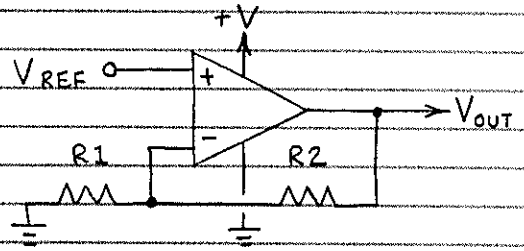
FUNCTION GENERATORS



THESE IC's GENERATE VARIOUS KINDS OF OUTPUT WAVES SUCH AS THOSE SHOWN HERE. THE FREQUENCY OF THE WAVES CAN BE CONTROLLED BY AN EXTERNAL RC CIRCUIT.

VOLTAGE REGULATORS

VOLTAGE REGULATORS CONVERT A VOLTAGE APPLIED TO THEIR INPUT INTO A FIXED OR VARIABLE (BUT USUALLY LOWER) VOLTAGE. IN MOST A SMALL, FIXED REFERENCE VOLTAGE (USUALLY A VOLT OR SO) IS APPLIED TO THE NON-INVERTING INPUT OF AN OP-AMP. THE RERERENCE VOLTAGE (OR V_{REF}) IS THEN AMPLIFIED BY THE RATIO OF THE FEEDBACK AND INPUT RESISTORS (THE GAIN). IF ONE OF THE RESISTORS IS A POTENTIOMETER, THE OUTPUT VOLTAGE (V_{OUT}) CAN BE VARIED FROM V_{REF} TO +V (THE CHIP SUPPLY VOLTAGE). ACTUAL IC REGULATORS INCLUDE EXTRA TRANSISTORS TO PROVIDE V_{REF} AND TO ALLOW THE CHIP TO DRIVE LOADS THAT REQUIRE MORE POWER THAN AN OP-AMP ALONE CAN DELIVER.



BASIC VOLTAGE REGULATOR

☐ IC REGULATORS — MANY TYPES OF FIXED AND VARIABLE OUTPUT IC REGULATORS ARE AVAILABLE. MOST ARE INSTALLED IN PACKAGES MADE OF METAL OR HAVING METAL TABS TO HELP RADIATE EXCESSIVE HEAT INTO THE SURROUNDING AIR. CAUTION: MANUFACTURER'S OPERATING INSTRUCTIONS AND STANDARD SAFETY PRECAUTIONS MUST BE FOLLOWED FOR BEST RESULTS.

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OTHER LINEAR IC's

THERE ARE NUMEROUS SPECIAL FUNCTION LINEAR IC's, MANY OF WHICH INCORPORATE OP-AMPS. FOR EXAMPLE:

☐ AUDIO AMPLIFIERS — MANY KINDS AVAILABLE. SOME INCLUDE TWO AMPLIFIERS ON ONE CHIP (FOR STEREO).

☐ PHASE-LOCKED LOOPS — BASED ON AN OLD BUT CLEVER IDEA IN WHICH AN ON-CHIP OSCILLATOR DUPLICATES (OR TRACKS) THE FREQUENCY OF AN INCOMING SIGNAL. USED TO DETECT THE PRESENCE OF CERTAIN FREQUENCIES (LIKE TOUCH-TONE® TONES) AND TO DEMODULATE FM RADIO SIGNALS.

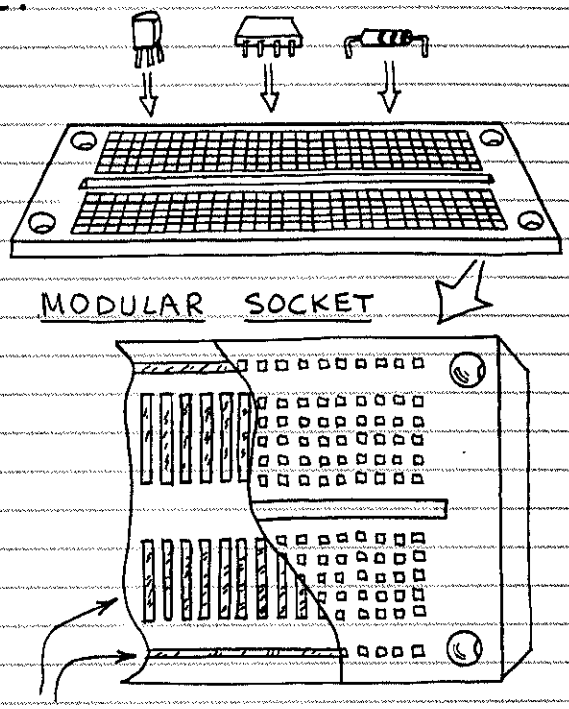
☐ OTHER LINEAR IC's — INCLUDED ARE MANY KINDS OF CHIPS FOR TELEPHONE, RADIO, TELEVISION AND COMPUTER COMMUNICATIONS. ALSO, MANY KINDS OF IC'S THAT DETECT TEMPERATURE, LIGHT AND PRESSURE.

8. CIRCUIT ASSEMBLY TIPS

THERE ARE SEVERAL WAYS TO MAKE EITHER TEMPORARY OR PERMANENT VERSIONS OF ELECTRONIC CIRCUITS. IN THIS CHAPTER WE'LL LOOK AT SOME CIRCUIT ASSEMBLY TIPS YOU MAY FIND HELPFUL.

TEMPORARY CIRCUITS

IT'S ALWAYS WISE TO BUILD A TEMPORARY VERSION OF A CIRCUIT BEFORE ASSEMBLING IT IN PERMANENT FORM. YOU CAN THEN MAKE CHANGES AND FIND OUT HOW WELL THE CIRCUIT WORKS. BY FAR THE MOST IMPORTANT TOOL FOR TEMPORARY CIRCUIT ASSEMBLY IS THE PLASTIC SOLDERLESS MODULAR BREADBOARD SOCKET. IT'S A GOOD IDEA TO KEEP SEVERAL ON YOUR WORKBENCH. THEY WILL LET YOU BUILD ENTIRE CIRCUITS IN MINUTES. USE "JUMPER" WIRES TO INTERCONNECT PARTS WHOSE LEADS ARE NOT INSERTED IN THE SAME ROW OF TERMINALS. TO AVOID BENDING THEIR PINS (AND PRICKING YOUR FINGERS), INSTALL AND REMOVE IC'S CAREFULLY.



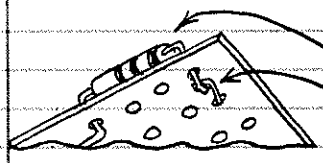
CUTAWAY SHOWING COMMON TERMINAL CONNECTIONS.

HINT: INSTALL SOCKET ON BASE AND ADD POTENTIOMETERS, BATTERY, LEDs, SWITCHES, ETC.

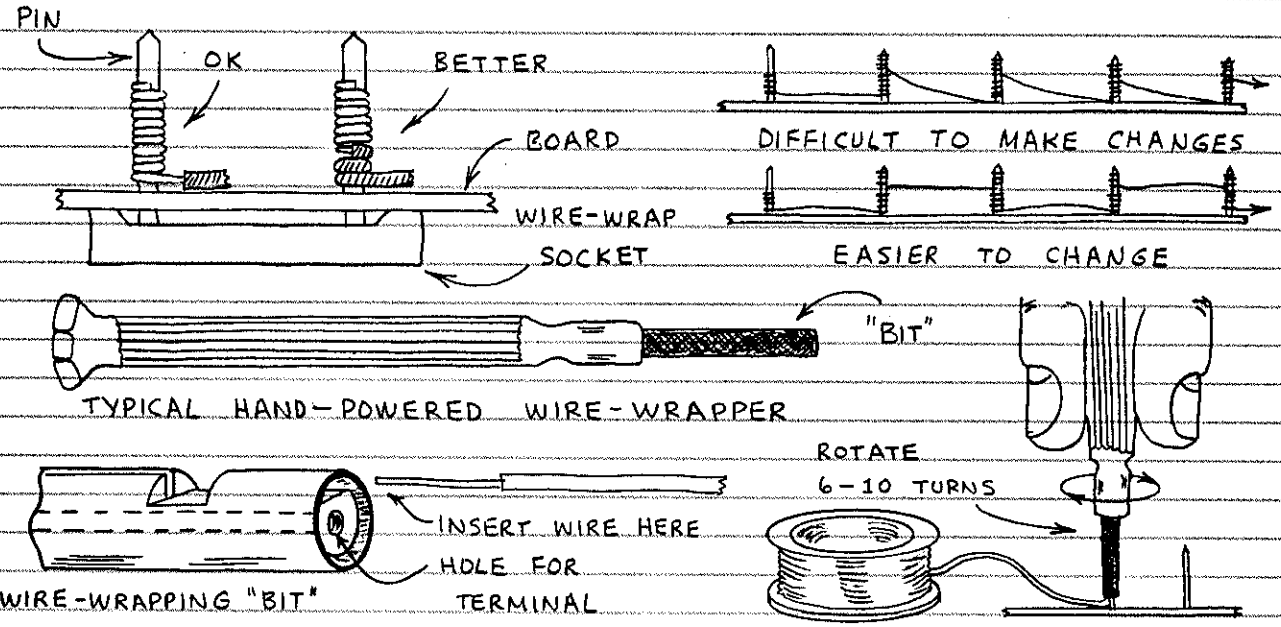
PERMANENT CIRCUITS

WITH THE EXCEPTION OF SOME VERY SIMPLE CIRCUITS, MOST PERMANENT CIRCUITS ARE ASSEMBLED ON SOME FORM OF CIRCUIT BOARD.

☐ PERFORATED BOARD CONSTRUCTION — COMPONENT LEADS ARE INSERTED THROUGH PERFORATIONS IN A PHENOLIC OR SIMILAR BOARD AND SOLDERED TOGETHER ON THE BACK SIDE OF THE BOARD. OFTEN INSULATED CONNECTION WIRES MUST BE USED. ONCE ASSEMBLED, "PERFBOARD" CIRCUITS ARE DIFFICULT TO REPAIR SINCE COMPONENT LEADS ARE OFTEN TWISTED AND SOLDERED.



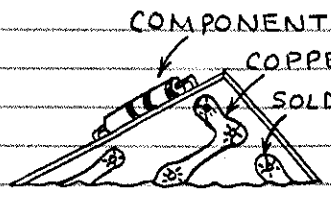
☐ WIRE-WRAP — FASTEST WAY TO ASSEMBLE CIRCUITS THAT USE MORE THAN A FEW IC's. USE WIRE-WRAP IC SOCKETS (WITH SQUARE CONNECTION PINS). BOTH HAND AND MOTOR POWERED WRAPPING TOOLS ARE AVAILABLE. IF YOU USE THE KIND THAT REQUIRES SOME OF THE WIRE'S INSULATION BE REMOVED, WRAP A FEW TURNS OF INSULATED WIRE AROUND THE CONNECTION PIN TO STRENGTHEN THE CONNECTION.



☐ PRINTED CIRCUIT (PC) — PROVIDES THE NEATEST AND MOST PROFESSIONAL APPEARING COMPLETED CIRCUIT. SOCKETS NOT REQUIRED, BUT COMPONENT LEADS MUST BE SOLDERED TO THE COPPER PATTERNS ON THE BOARD. THERE ARE MANY TYPES OF PC BOARDS. TWO TYPES USED BY EXPERIMENTERS ARE:

1. PRE-ETCHED PERFORATED GRID BOARDS HAVE A ROUND, COPPER FOIL SOLDER PAD AT EACH HOLE. ON MANY BOARDS ROWS OF HOLES ARE CONNECTED BY COMMON COPPER FOIL STRIPS (LIKE A SOLDERLESS BREADBOARD). IT'S USUALLY NECESSARY TO JOIN SOME OF THE CONTACTS ON THE BOARD WITH "JUMPERS" (SHORT LENGTHS OF INSULATED HOOKUP OR WRAPPING WIRE).

2. CUSTOM PC BOARDS ARE MADE BY APPLYING A TAPE OR CHEMICAL COATING (THE "RESIST") TO THE CLEAN COPPER FOIL OF A PC BOARD. THE UNCOATED COPPER IS THEN CHEMICALLY ETCHED AWAY, LEAVING BEHIND A FOIL WIRING PATTERN. HOLES ARE DRILLED FOR COMPONENT LEADS. TAKES LOTS OF TIME, BUT PRODUCES NEAT CIRCUITS.



HOW TO SOLDER

GOOD SOLDERING PRACTICES ARE ESSENTIAL FOR RELIABLE OPERATION OF A CIRCUIT WITH SOLDERED CONNECTIONS. HERE ARE SIX STEPS FOR SUCCESSFUL SOLDERING:

1. ALWAYS USE A LOW-WATTAGE SOLDERING IRON (25 TO 40 WATTS). BE SURE TO TIN THE TIP ACCORDING TO THE MANUFACTURER'S INSTRUCTIONS.

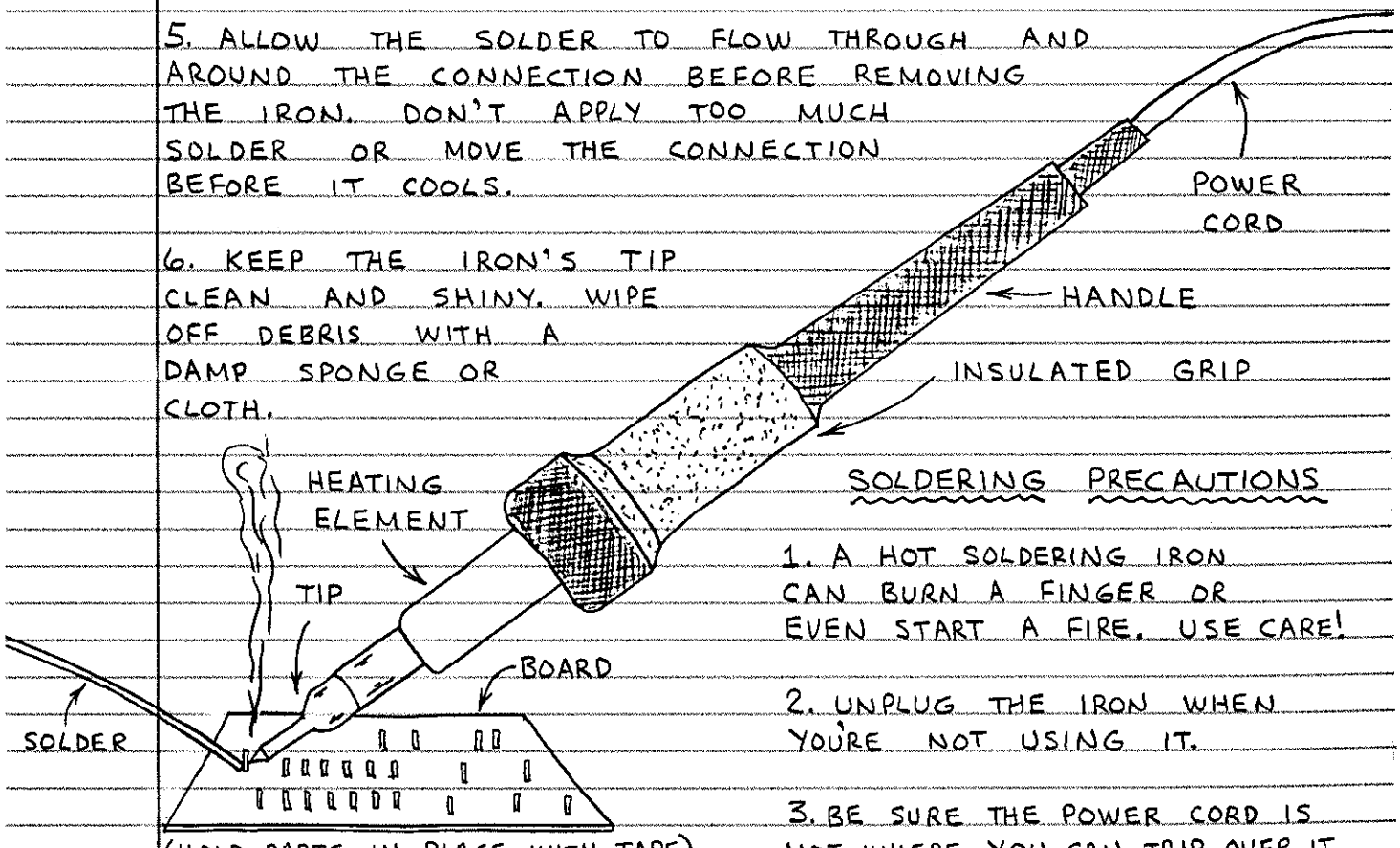
2. ALWAYS USE ROSIN CORE SOLDER WHEN SOLDERING ELECTRONIC COMPONENTS. NEVER USE ACID CORE SOLDER SINCE IT WILL CORRODE THE SOLDERED LEAD.

3. SOLDER DOES NOT ADHERE TO PAINT, GREASE, OIL, WAX OR MELTED INSULATION. REMOVE ALL SUCH FOREIGN MATTER WITH A SOLVENT, STEEL WOOL OR FINE SANDPAPER. ALWAYS BUFF THE COPPER FOIL OF A PC BOARD WITH STEEL WOOL BEFORE SOLDERING. (THE COPPER SHOULD BE SHINY.)

4. TO SOLDER, FIRST HEAT THE CONNECTION (NOT THE SOLDER!) FOR A FEW SECONDS WITH THE HOT TIP OF THE IRON. THEN LEAVE THE IRON IN PLACE AND APPLY SOLDER.

5. ALLOW THE SOLDER TO FLOW THROUGH AND AROUND THE CONNECTION BEFORE REMOVING THE IRON. DON'T APPLY TOO MUCH SOLDER OR MOVE THE CONNECTION BEFORE IT COOLS.

6. KEEP THE IRON'S TIP CLEAN AND SHINY. WIPE OFF DEBRIS WITH A DAMP SPONGE OR CLOTH.



SOLDERING PRECAUTIONS

1. A HOT SOLDERING IRON CAN BURN A FINGER OR EVEN START A FIRE. USE CARE!

2. UNPLUG THE IRON WHEN YOU'RE NOT USING IT.

3. BE SURE THE POWER CORD IS NOT WHERE YOU CAN TRIP OVER IT.

POWERING ELECTRONIC CIRCUITS

☐ BATTERY POWER — MANY CIRCUITS USE SO LITTLE POWER THEY CAN BE POWERED BY BATTERIES. THIS KEEPS THE COMPLETED CIRCUIT COMPACT AND ALLOWS IT TO BE OPERATED ANYWHERE.

☐ SOLAR POWER — SOLAR CELLS CAN POWER YOUR CIRCUITS DIRECTLY. OR YOU CAN USE AN ARRAY OF SOLAR CELLS TO CHARGE A RECHARGEABLE BATTERY.

☐ LINE POWER - THE SIMPLEST LINE POWERED SUPPLY IS THE SO-CALLED AC ADAPTER. THESE MODULAR UNITS ARE COMPACT AND EASY TO USE. UNITS HAVING VARIOUS OUTPUT VOLTAGES AND CURRENTS ARE AVAILABLE. YOU CAN MAKE YOUR OWN LINE POWERED SUPPLY USING AN IC VOLTAGE REGULATOR.

☐ CAUTION — SAFETY SHOULD BE YOUR FIRST CONCERN WHEN BUILDING YOUR OWN LINE POWERED SUPPLY. THE POWER CORD MUST BE PROTECTED FROM THE SHARP EDGES OF A HOLE DRILLED IN A METAL CABINET. (USE A PLASTIC STRAIN RELIEF.) ALL CONNECTIONS TO THE AC LINE MUST BE INSIDE A FULLY ENCLOSED HOUSING! LEAVING SUCH CONNECTIONS EXPOSED IS A POTENTIAL SHOCK HAZARD. MAKE SURE ALL COMPONENTS THAT ARE CONNECTED TO THE AC LINE (SWITCHES, FUSES, TRANSFORMERS, ETC.) MEET OR EXCEED THE POWER REQUIREMENT OF YOUR CIRCUIT.

SUMMING UP CIRCUIT ASSEMBLY

THE REMAINDER OF THIS BOOK INCLUDES MANY CIRCUITS YOU CAN QUICKLY ASSEMBLE ON A SOLDERLESS BREADBOARD. CHANCES ARE YOU'LL WANT TO MAKE PERMANENT VERSIONS OF SOME. FOR BEST RESULTS, PLAN THE PROJECT CAREFULLY. A NEATLY ASSEMBLED PROJECT WILL BE MORE RELIABLE THAN ONE HASTILY ASSEMBLED.