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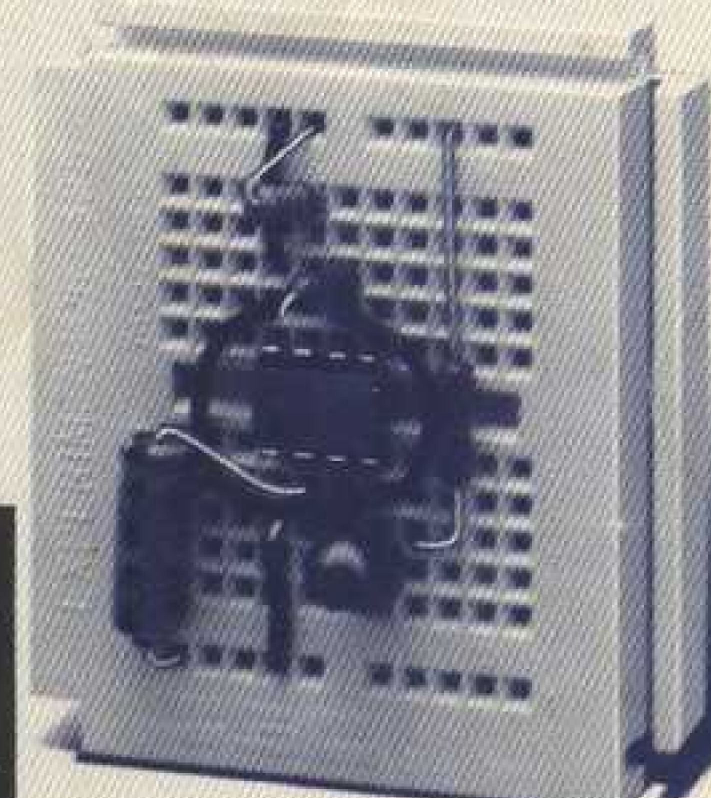
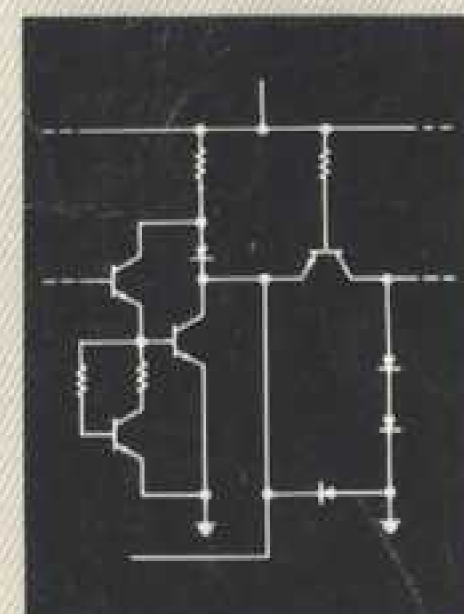
Engineer's Mini-Notebook

Basic Semiconductor Circuits





Forrest M. Mims III

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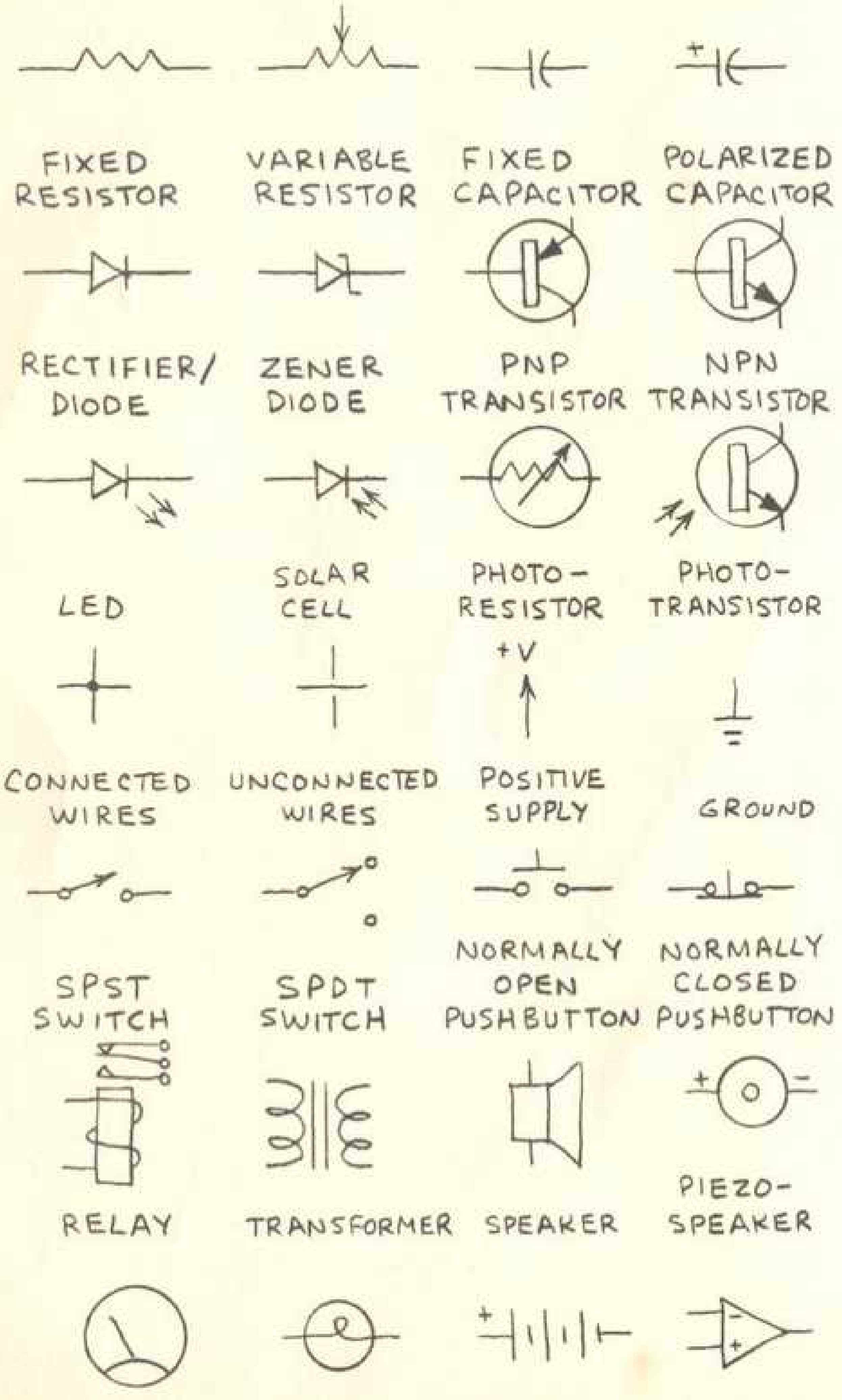
CIRCUIT SYMBOLS



ENGINEER'S MINI-NOTEBOOK

BASIC SEMICONDUCTOR CIRCUITS

BY

FORREST M. MIMS, III

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A SILICONCEPTS™ BOOK

PRINTED IN THE UNITED STATES OF AMERICA

THIS BOOK INCLUDES STANDARD APPLICATION CIRCUITS AND CIRCUITS DESIGNED BY THE AUTHOR. EACH CIRCUIT WAS ASSEMBLED AND TESTED BY THE AUTHOR AS THE BOOK WAS DEVELOPED. AFTER THE BOOK WAS COMPLETED, THE AUTHOR REASSEMBLED EACH CIRCUIT TO CHECK FOR ERRORS. WHILE REASONABLE CARE WAS EXERCISED IN THE PREPARATION OF THIS BOOK, VARIATIONS IN COMPONENT TOLERANCES AND CONSTRUCTION METHODS MAY CAUSE THE RESULTS YOU OBTAIN TO DIFFER FROM THOSE GIVEN HERE. THEREFORE THE AUTHOR AND RADIO SHACK ASSUME NO RESPONSIBILITY FOR THE SUITABILITY OF THIS BOOK'S CONTENTS FOR ANY APPLICATION. SINCE WE HAVE NO CONTROL OVER THE USE TO WHICH THE INFORMATION IN THIS BOOK IS PUT, WE ASSUME NO LIABILITY FOR ANY DAMAGES RESULTING FROM ITS USE. OF COURSE IT IS YOUR RESPONSIBILITY TO DETERMINE IF COMMERCIAL USE, SALE OR MANUFACTURE OF ANY DEVICE THAT INCORPORATES INFORMATION IN THIS BOOK INFRINGES ANY PATENTS, COPYRIGHTS OR OTHER RIGHTS.

DUE TO THE MANY INQUIRIES RECEIVED BY RADIO SHACK AND THE AUTHOR, IT IS NOT POSSIBLE TO PROVIDE PERSONAL RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION (CUSTOM CIRCUIT DESIGN, TECHNICAL ADVICE, TROUBLESHOOTING ADVICE, ETC.). IF YOU WISH TO LEARN MORE ABOUT ELECTRONICS, SEE OTHER BOOKS IN THIS SERIES AND RADIO SHACK'S "GETTING STARTED IN ELECTRONICS." ALSO, READ MAGAZINES LIKE <u>MODERN ELECTRONICS</u> AND <u>RADIO-ELECTRONICS</u>. THE AUTHOR WRITES A MONTHLY COLUMN, "ELECTRONICS NOTEBOOK," FOR <u>MODERN ELECTRONICS</u>.

CONTENTS

INTRODUCTION

IN THIS ERA OF INTEGRATED CIRCUIT MICROCHIPS, THE SIMPLICITY AND ECONOMY OF CIRCUITS MADE FROM INDIVIDUAL COMPONENTS ARE OFTEN OVERLOOKED. THE CIRCUITS THAT FOLLOW ILLUSTRATE MORE THAN 75 APPLICATIONS FOR SUCH BASIC COMPONENTS AS DIODES, TRANSISTORS, SCRS, AND TRIACS. THESE CIRCUITS ARE PRECEEDED BY SECTIONS ON RESISTORS AND CAPACITORS SINCE THESE COMPONENTS ARE AN ESSENTIAL INGREDIENT IN NEARLY ALL SEMICONDUCTOR CIRCUITS.

FOR MORE INFORMATION ABOUT THE COMPONENTS USED IN THE CIRCUITS THAT FOLLOW, SEE "GETTING STARTED IN ELECTRONICS" (RADIO SHACK, 1983). THIS BOOK COVERS BASIC ELECTRONICS AND INCLUDES 100 TESTED CIRCUITS. ALSO, SEE OTHER TITLES IN THE "ENGINEER'S MINI-NOTEBOOK" SERIES.

CIRCUIT ASSEMBLY TIPS

TEST VERSIONS OF THE CIRCUITS IN THIS BOOK WERE ASSEMBLED ON RADIO SHACK MODULAR BREADBOARD SOCKETS. AFTER ASSEMBLING AND TESTING A CIRCUIT ON A BREADBOARD, YOU CAN ASSEMBLE A PERMANENT VERSION ON A CIRCUIT BOARD AND INSTALL IT IN AN ENCLOSURE. THOUGH EACH CIRCUIT INCLUDES SPECIFIC COMPONENT VALUES, SUBSTITUTIONS ARE USUALLY OK IF VOLTAGE, CURRENT, AND POWER RATINGS ARE OBSERVED. FOR INSTANCE, A 1.2K RESISTOR CAN USUALLY BE SUBSTITUTED FOR A 1K UNIT. A 100K POTENTIOMETER CAN BE USED IN PLACE OF A 50K UNIT. AND <u>MANY</u> NPN TRANSISTORS CAN BE USED FOR THE POPULAR 2N2222. FOR MORE, SEE "GETTING STARTED IN ELECTRONICS."

RESISTORS

RESISTORS RESIST THE FLOW OF AN ELECTRICAL CURRENT. THE UNIT OF RESISTANCE IS THE <u>OHM</u> (Ω). A POTENTIAL DIFFERENCE OF ONE VOLT WILL FORCE A CURRENT OF ONE AMPERE THROUGH A RESISTANCE OF ONE OHM.

OHM'S LAW

<u>VOLTAGE</u> (V) IS THE POTENTIAL DIFFERENCE ACROSS A RESISTOR. <u>CURRENT</u> (I) IS THE FLOW OF ELECTRONS THROUGH A RESISTOR. GIVEN ANY TWO VALUES OF RESISTANCE, VOLTAGE, OR CURRENT, THE THIRD VALUE CAN BE CALCULATED FROM OHM'S LAW:

$V = I \times R$ $\quad$ $I = V/R$ $\quad$ $R = V/I$

THE <u>POWER</u> DISSIPATED IN A RESISTOR CAN ALSO BE CALCULATED:

$P = V \times I$ $\quad$ $P = I^2 R$

THE UNIT OF POWER IS THE <u>WATT</u>. IT IS IMPORTANT TO BE SURE THAT ALL VALUES ARE EXPRESSED PROPERLY WHEN USING OHM'S LAW. FOR EXAMPLE, 65 MILLIVOLTS SHOULD BE EXPRESSED AS 0.065 VOLTS. 470 MILLIWATTS SHOULD BE EXPRESSED AS 0.47 WATTS. A 47K RESISTOR HAS A RESISTANCE OF 47 × 1,000 OR 47,000 OHMS. A 2.2M RESISTOR HAS A RESISTANCE OF 2.2 × 1,000,000 OR 2,200,000 OHMS.

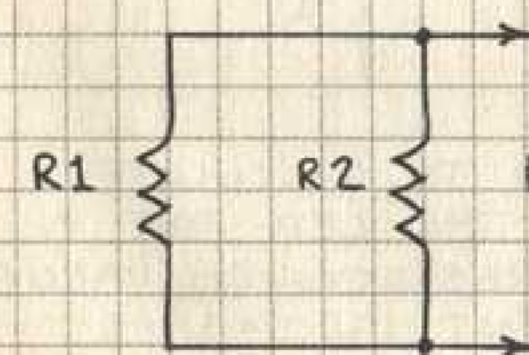
USUALLY YOU MAY USE A RESISTOR WITH A VALUE WITHIN 10-20% OF THE REQUIRED VALUE. <u>ALWAYS</u> USE RESISTORS HAVING THE PROPER POWER RATING.

RESISTORS IN SERIES

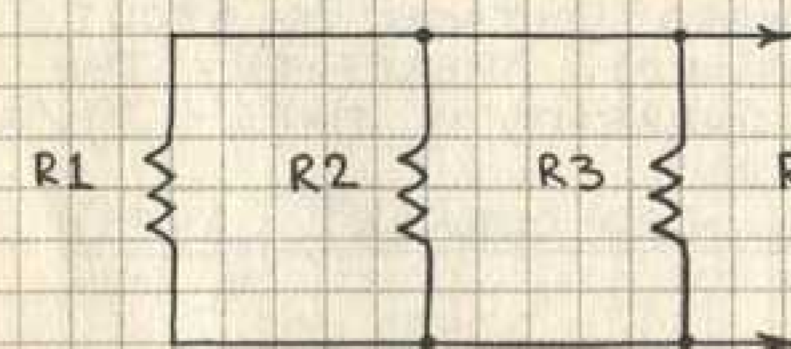
TOTAL RESISTANCE (R_T) = R1 + R2

TOTAL RESISTANCE (R_T) = R1 + R2 + R3

RESISTORS IN PARALLEL



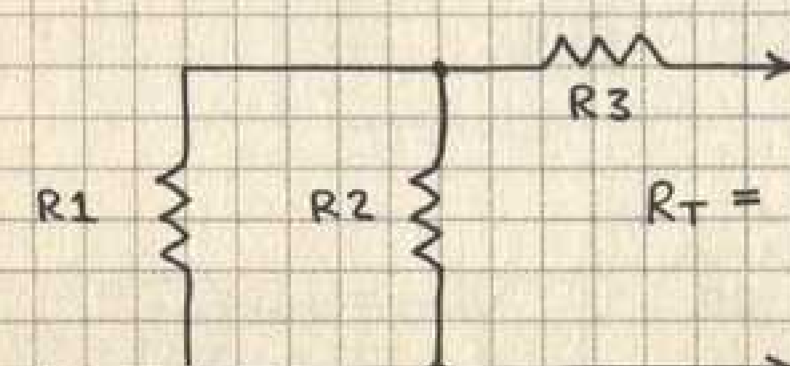
$$R_T = \frac{R1 \times R2}{R1 + R2}$$



$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}}$$

IF R1 = R2 = R3, THEN R_T = R1 / 3.

RESISTORS IN SERIES / PARALLEL

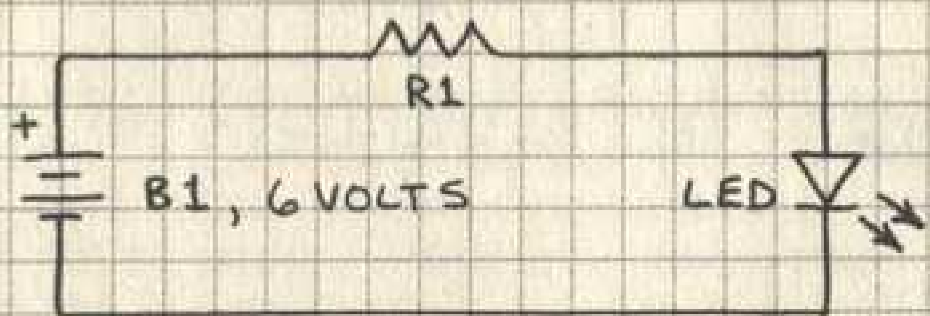


$$R_T = \frac{R1 \times R2}{R1 + R2} + R3$$

HOW TO USE RESISTORS

CURRENT LIMITING

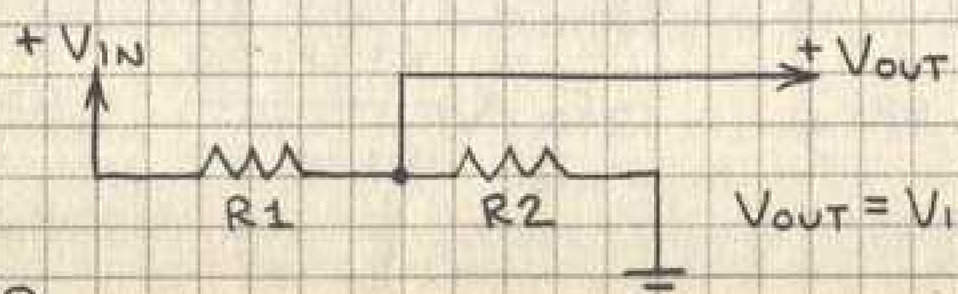
A RESISTOR CAN BE PLACED IN SERIES WITH A LAMP, LED, SPEAKER, TRANSISTOR, OR OTHER COMPONENT TO REDUCE THE FLOW OF CURRENT THROUGH THE DEVICE. FOR EXAMPLE:



OHM'S LAW CAN BE USED TO CALCULATE THE CURRENT THROUGH THE LED FOR A RANGE OF STANDARD RESISTANCE VALUES. THE FORMULA FOR CURRENT IS $I = V/R$. AN LED DOES NOT BEGIN TO CONDUCT UNTIL THE FORWARD VOLTAGE IS ABOUT 1.7 VOLTS (RED LED). THEREFORE, THE FORMULA FOR CURRENT IS $I = (6-1.7)/R$.

R1 (OHMS	LED CURRENT (AMPS)
100	.043
150	.029
220	.020
270	.016
330	.013

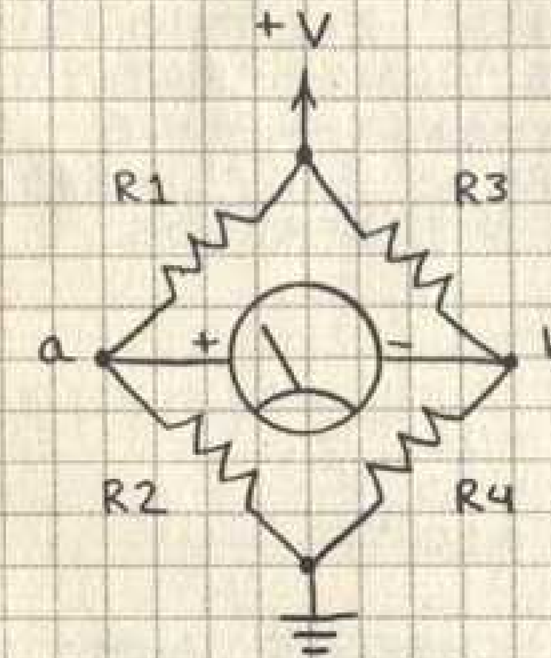
VOLTAGE DIVISION



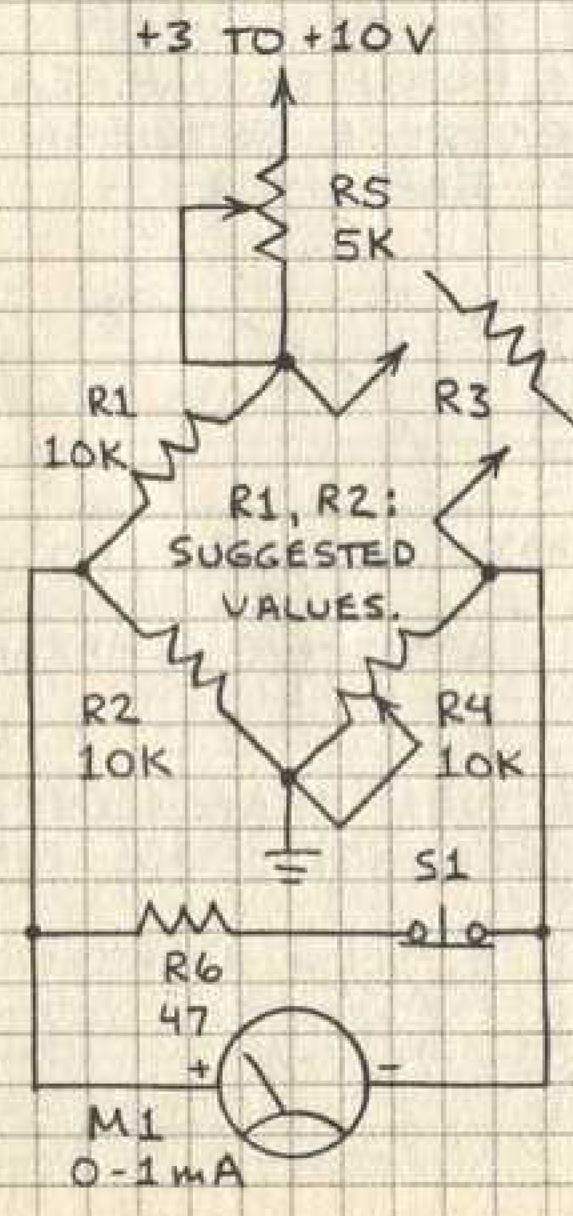
$$V_{OUT} = V_{IN}\left(\frac{R2}{R1+R2}\right)$$

WHEATSTONE BRIDGE

THE WHEATSTONE BRIDGE PERMITS <u>VERY</u> ACCURATE MEASUREMENTS OF RESISTANCE. HERE IS THE BASIC CIRCUIT:



R1−R2 AND R3−R4 FORM TWO VOLTAGE DIVIDERS. WHEN THE VOLTAGE AT a EQUALS THE VOLTAGE AT b, THE METER INDICATES NO VOLTAGE AND THE BRIDGE IS SAID TO BE <u>BALANCED</u>. WHEN THIS OCCURS, THEN: $R1/R3 = R2/R4$.



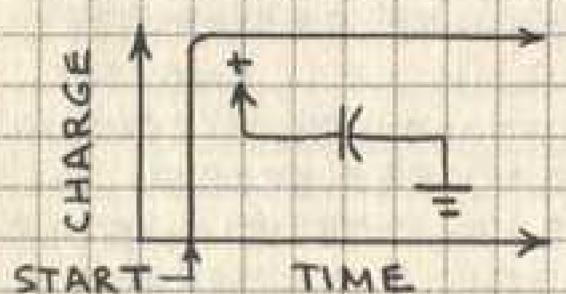
THE BRIDGE SHOWN HERE PERMITS THE ACCURATE MEASUREMENT OF AN UNKNOWN RESISTANCE (R3). R1 AND R2 SHOULD BE PRECISION (±1%) RESISTORS. R4 IS A POTENTIOMETER WITH A CALIBRATED DIAL. RS IS USED TO REGULATE THE CURRENT FROM THE POWER SUPPLY. R6 AND S1 FORM A SHUNT THAT PROTECTS M1. ADJUST R4 UNTIL M1 = 0. PRESS S1 AND REPEAT. R3 = R4. IF $R1 \neq R2$, THEN $R3 = (R1 \times R4) / R2$.

CAPACITORS

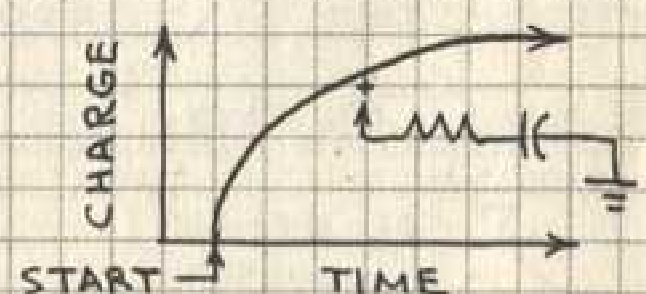
CAPACITORS STORE AN ELECTRICAL CHARGE. THE UNIT OF CAPACITANCE IS THE <u>FARAD</u>. A 1-FARAD CAPACITOR CONNECTED TO A 1-VOLT SUPPLY WILL STORE A CHARGE OF 6.28×10^{18} ELECTRONS. MOST CAPACITORS HAVE CONSIDERABLY LESS CAPACITY. VALUES COMMONLY RANGE FROM A FEW PICOFARADS (10^{-12} FARAD) TO A FEW THOUSAND MICROFARADS (10^{-6} FARAD).

1 FARAD = 1 F
1 MICROFARAD = 1 μF = 10^{-6} F
1 NANOFARAD = 1 nF = 10^{-9} F
1 PICO FARAD = 1 pF = 10^{-12} F

A CAPACITOR CAN BE CHARGED ALMOST INSTANTLY BY CONNECTING ITS LEADS DIRECTLY ACROSS A POWER SUPPLY. THE CHARGING TIME CAN BE INCREASED BY INSERTING A RESISTOR BETWEEN THE SUPPLY AND THE CAPACITOR.

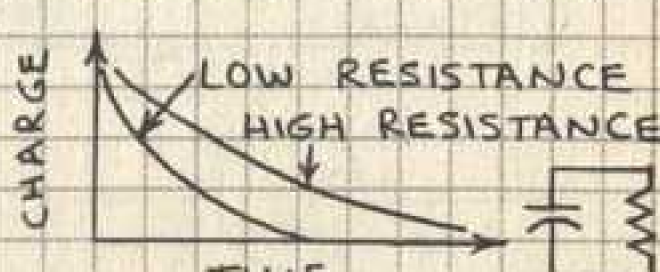


DIRECT CHARGE

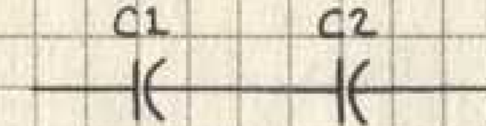


RESISTIVE CHARGE

A CHARGED CAPACITOR WILL GRADUALLY LOSE ITS CHARGE THROUGH LEAKAGE. THE DISCHARGE TIME CAN BE REDUCED BY CONNECTING A RESISTOR ACROSS THE CAPACITOR'S TWO LEADS:



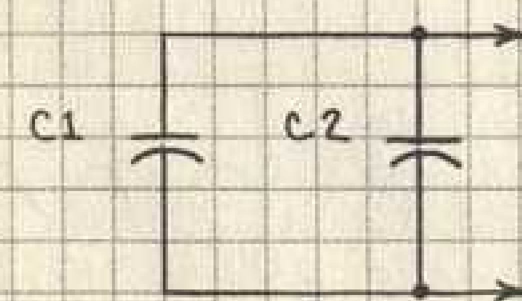
CAPACITORS IN SERIES



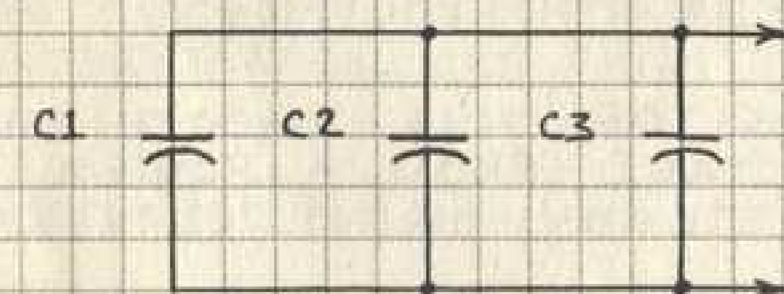
TOTAL CAPACITANCE (C_T) = $\frac{C1 \times C2}{C1 + C2}$

TOTAL CAPACITANCE (C_T) = $\frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$

CAPACITORS IN PARALLEL



$C_T = C1 + C2$



$C_T = C1 + C2 + C3$

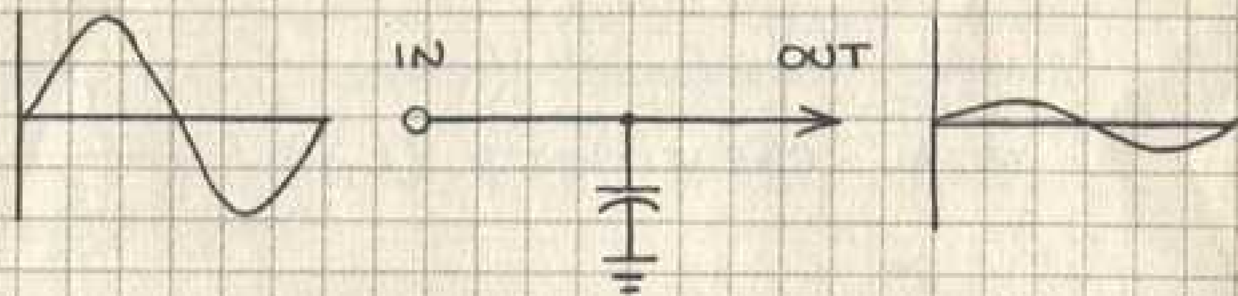
<u>WARNING!</u>

MOST CAPACITORS CAN RETAIN A CHARGE FOR A CONSIDERABLE TIME AFTER THE CHARGING SUPPLY HAS BEEN SWITCHED OFF. THEREFORE <u>USE CAUTION</u> WHEN WORKING WITH CAPACITORS. A LARGE ELECTROLYTIC CAPACITOR CHARGED TO ONLY 5 TO 10 VOLTS CAN MELT THE TIP OF A SCREWDRIVER SHORTED ACROSS ITS LEADS! HIGH-VOLTAGE CAPACITORS IN TV SETS AND PHOTOFLASH UNITS CAN STORE A <u>LETHAL</u> CHARGE!

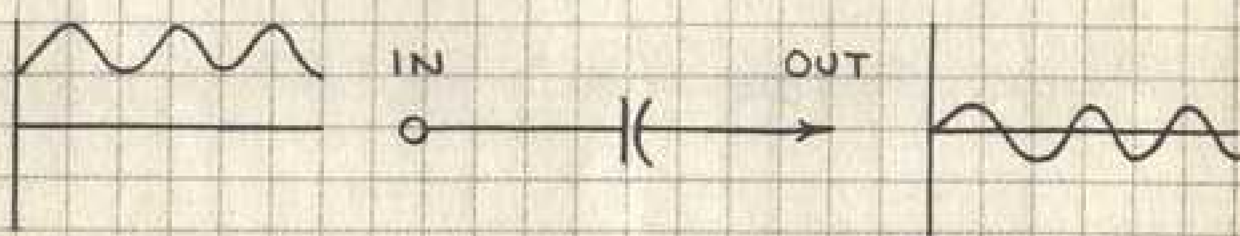
HOW TO USE CAPACITORS

SIGNAL FILTERING

A SINGLE CAPACITOR CAN DIVERT AN UNWANTED SIGNAL TO GROUND:

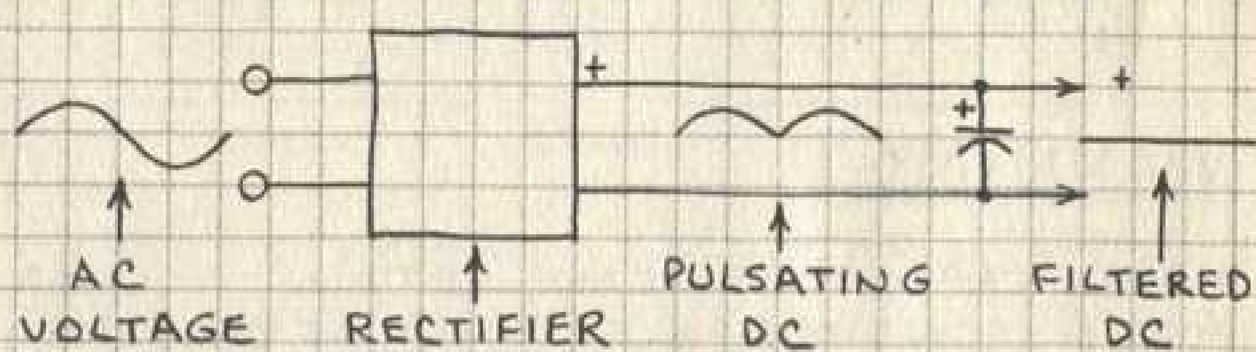


A SINGLE CAPACITOR CAN REMOVE AN UNWANTED DC COMPONENT FROM A FLUCTUATING SIGNAL:



POWER SUPPLY FILTERING

A LARGE CAPACITOR WILL SMOOTH THE PULSATING VOLTAGE FROM A POWER SUPPLY INTO STEADY DIRECT CURRENT:



SPIKE AND NOISE SUPPRESSION

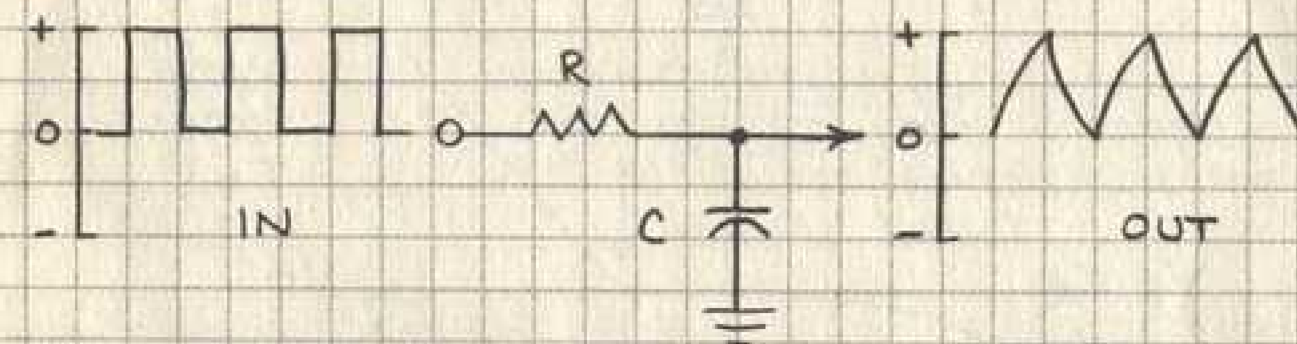
A 0.1 μF CAPACITOR ACROSS THE POWER SUPPLY PINS OF A LOGIC CHIP WILL HELP SUPPRESS FALSE TRIGGERING CAUSED BY BRIEF POWER SUPPLY NOISE SPIKES.

RESISTOR-CAPACITOR CIRCUITS

AMONG THE MOST IMPORTANT OF ALL CIRCUITS ARE THE BASIC RESISTOR-CAPACITOR (RC) CIRCUITS:

INTEGRATOR

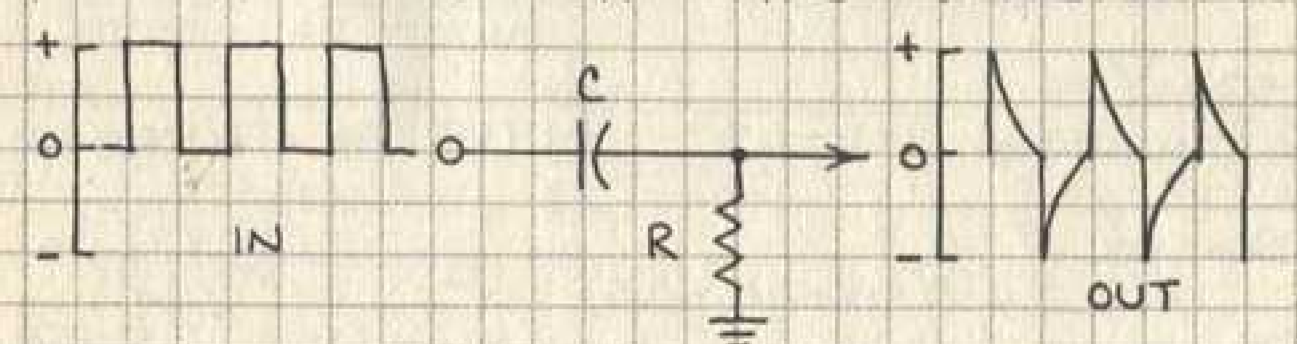
THE INTEGRATOR IS AN RC CIRCUIT THAT TRANSFORMS AN INCOMING SQUARE WAVE INTO A TRIANGLE WAVE:



R×C IS THE <u>TIME CONSTANT</u> OF THE CIRCUIT. RC MUST BE AT LEAST 10 TIMES THE PERIOD OF THE INPUT SIGNAL. IF NOT, THE AMPLITUDE OF THE OUTPUT SIGNAL WILL BE REDUCED. THE CIRCUIT WILL THEN BE A LOW-PASS FILTER THAT BLOCKS HIGH FREQUENCIES.

DIFFERENTIATOR

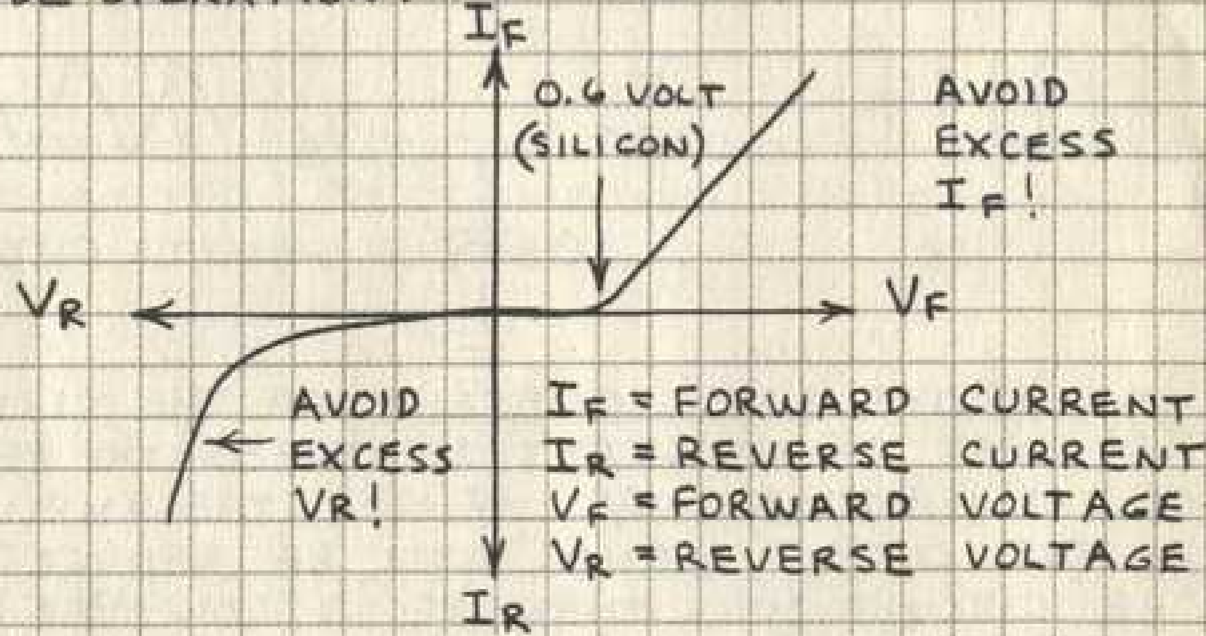
THE DIFFERENTIATOR IS AN RC CIRCUIT THAT TRANSFORMS AN INCOMING SQUARE WAVE INTO A PULSED OR SPIKED WAVEFORM:



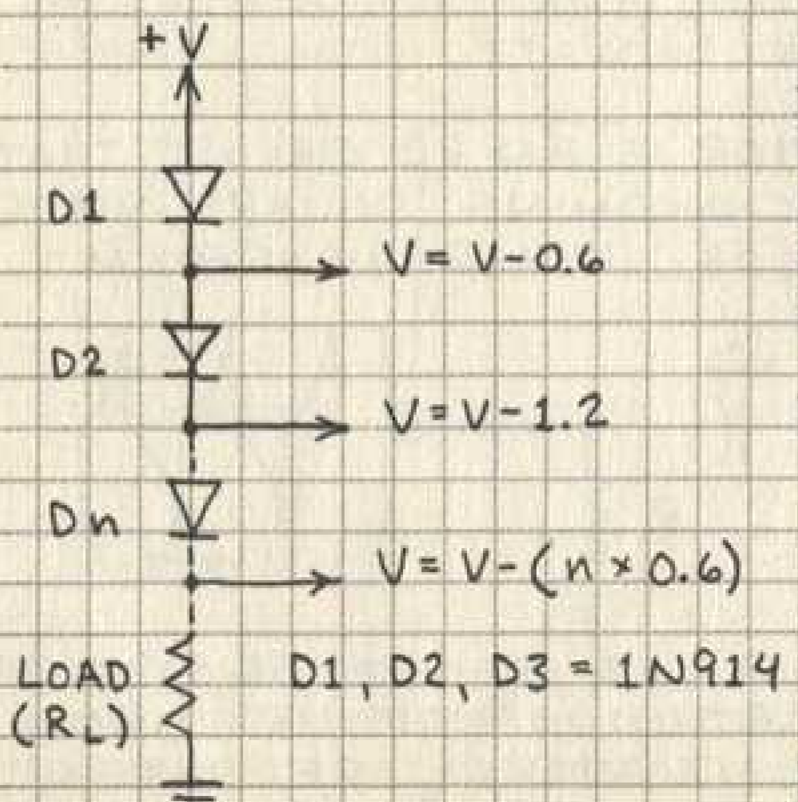
THE RC TIME CONSTANT SHOULD BE 1/10 (OR LESS) OF THE DURATION OF THE INCOMING PULSES. DIFFERENTIATORS ARE OFTEN USED TO CREATE TRIGGER PULSES.

DIODES AND RECTIFIERS

DIODES AND RECTIFIERS ARE SEMICONDUCTOR DEVICES THAT CONDUCT ELECTRICITY IN ONLY ONE DIRECTION. IT IS IMPORTANT TO UNDERSTAND THAT A DIODE DOES NOT BEGIN TO CONDUCT UNTIL THE FORWARD VOLTAGE REACHES A THRESHOLD POINT. FOR SILICON DIODES THIS VOLTAGE IS ABOUT 0.6 VOLT. FOR GERMANIUM DIODES IT IS ABOUT 0.3 VOLT. THIS GRAPH SUMS UP DIODE OPERATION:

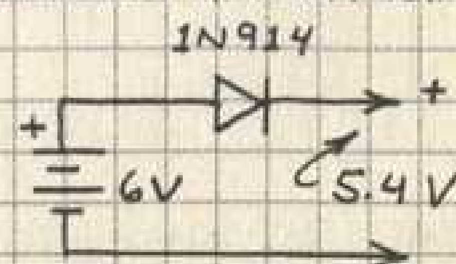


VOLTAGE DROPPER



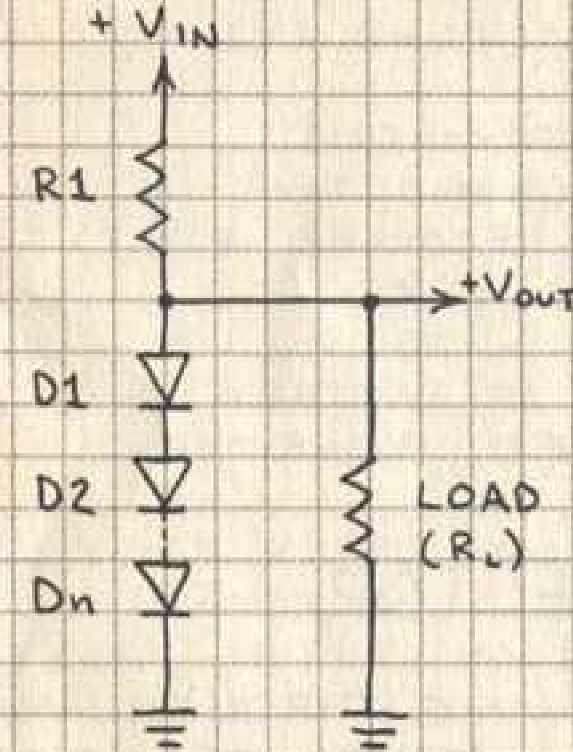
THIS CIRCUIT WILL REDUCE VOLTAGE FROM A POWER SUPPLY BY 0.6 VOLT PER DIODE.

TYPICAL APPLICATION:



ALLOWS 6-VOLTS TO POWER TTL CHIP.

VOLTAGE REGULATOR

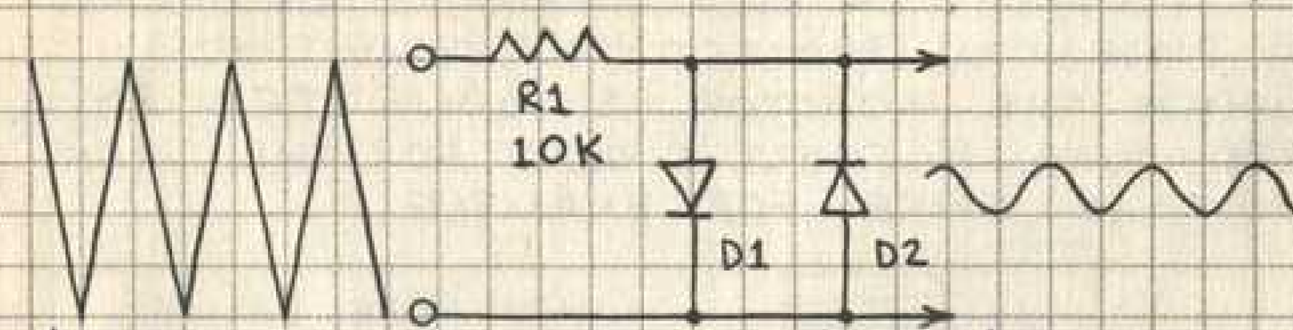


THIS CIRCUIT WILL SUPPLY A STEADY OUTPUT VOLTAGE EQUAL TO THE SUM OF THE TURN-ON (THRESHOLD) VOLTAGE OF DIODES D1 – Dn. THEREFORE, $V_{OUT} = 0.6 \times (D1 + D2 + Dn)$.

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

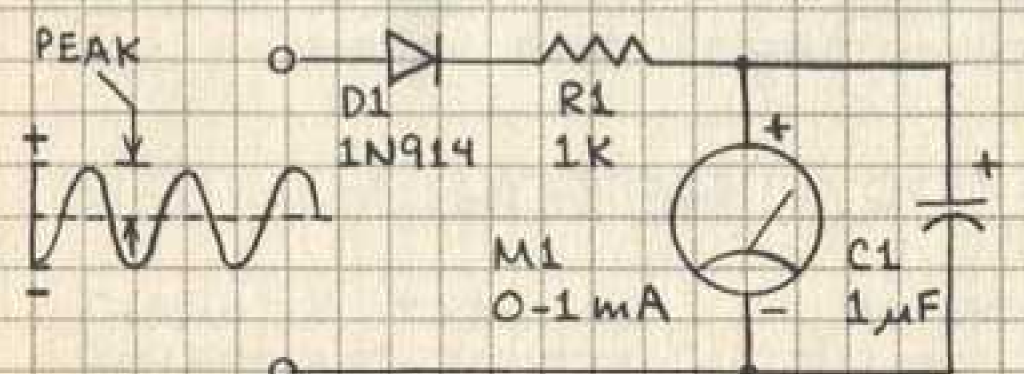
<u>CAUTION</u>: D1 AND R1 <u>MUST</u> HAVE PROPER POWER RATING. (USE OHM'S LAW.)

TRIANGLE-TO-SINE WAVE



±2.5-VOLT TRIANGLE WAVE   D1, D2 = 1N914   ±0.5-VOLT SINE WAVE

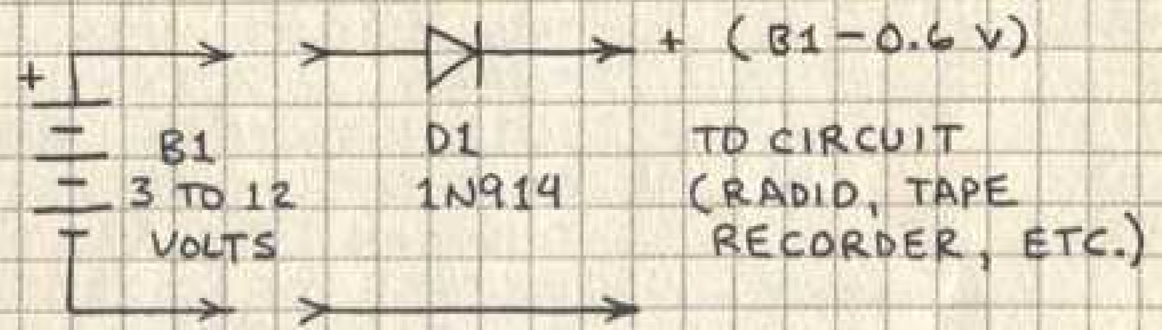
PEAK-READING VOLTMETER



FOR BEST RESULTS, USE DIGITAL MULTIMETER FOR M1. SET TO READ VOLTAGE.

FREQUENCY OF INCOMING SIGNAL MUST BE HIGH ENOUGH TO KEEP C1 CHARGED.

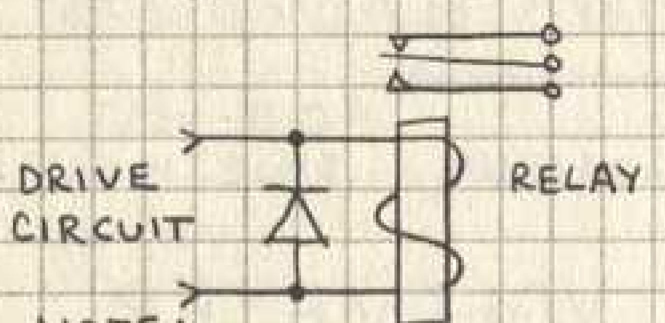
REVERSE-POLARITY PROTECTOR



DIODE PROTECTS CIRCUIT IF BATTERY IS INSTALLED WITH REVERSED POLARITY.

TRANSIENT PROTECTOR

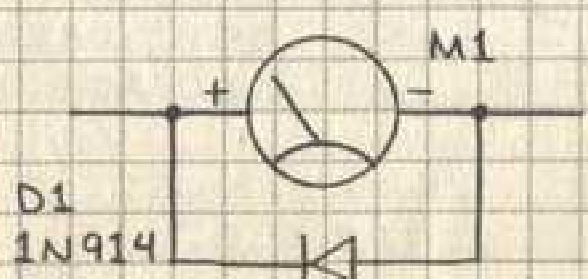
WHEN THE CURRENT FLOWING THROUGH AN INDUCTOR IS SUDDENLY SWITCHED OFF, THE COLLAPSING MAGNETIC FIELD WILL GENERATE A HIGH VOLTAGE IN THE INDUCTOR'S COILS. THIS VOLTAGE SPIKE MAY HAVE AN AMPLITUDE OF HUNDREDS OR EVEN THOUSANDS OF VOLTS. A DIODE CAN PROTECT THE CIRCUIT TO WHICH THE INDUCTOR IS CONNECTED BY PROVIDING A SHORT CIRCUIT FOR THE HIGH VOLTAGE SPIKE. FOR EXAMPLE:



WHEN THE DRIVE CIRCUIT SWITCHES THE RELAY OFF, A HIGH-VOLTAGE SPIKE IS GENERATED IN THE RELAY'S COIL. D1 SHORT CIRCUITS THIS SPIKE.

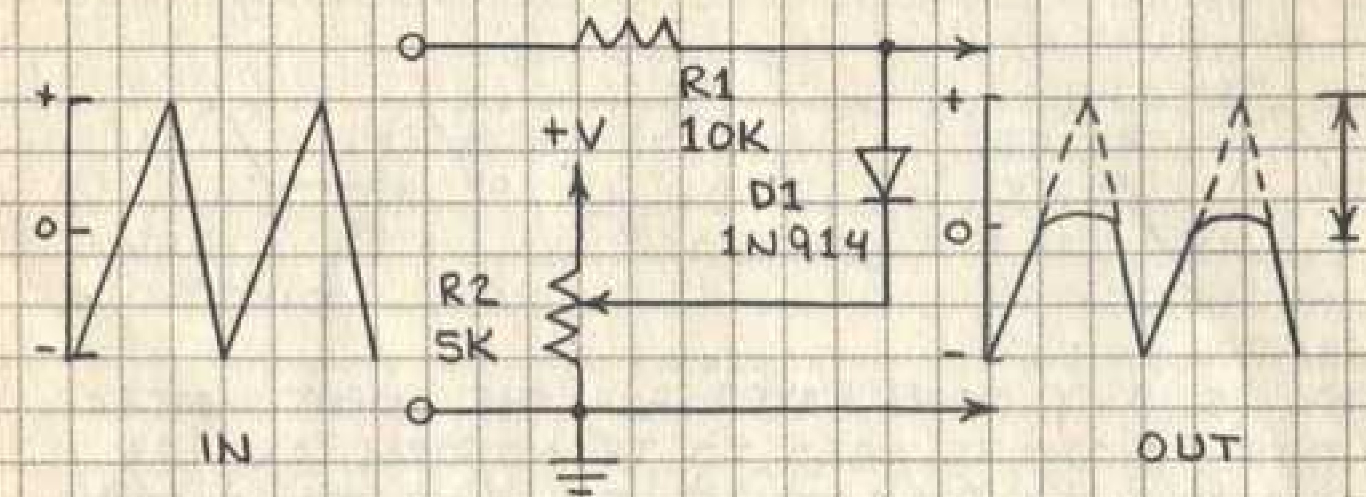
NOTE:
D1 INEFFECTIVE DURING TURN-ON TIME.

METER PROTECTOR



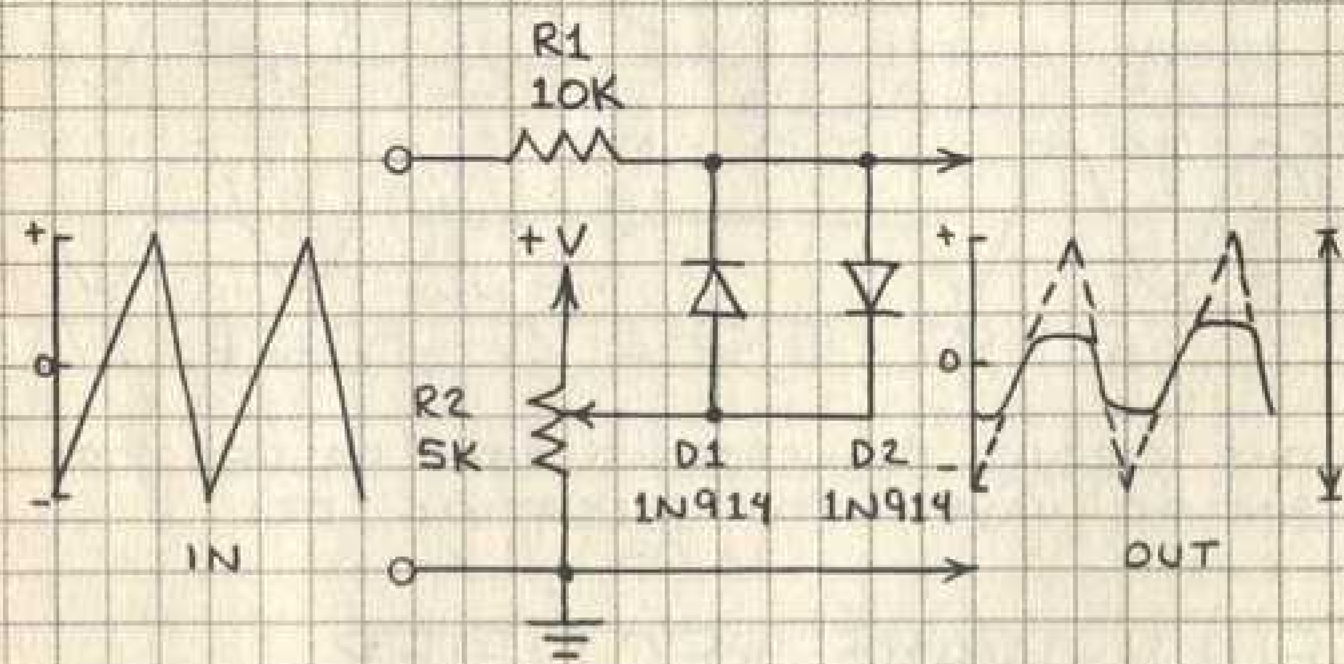
CONNECT A DIODE ACROSS THE TERMINALS OF A METER TO PROVIDE REVERSE CURRENT PROTECTION.

ADJUSTABLE WAVEFORM CLIPPER



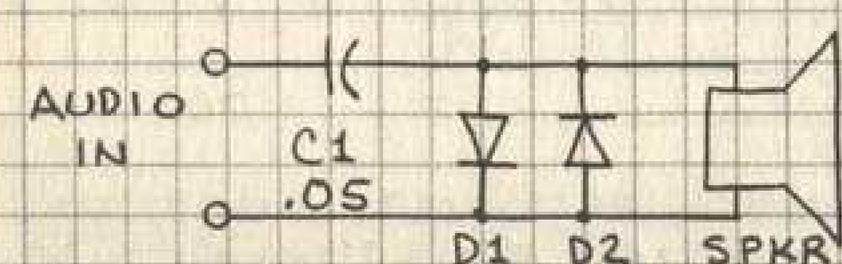
ADJUST R2 TO CONTROL CLIPPING AMPLITUDE. +V SHOULD BE A VOLT OR SO HIGHER THAN PEAK INPUT VOLTAGE.

ADJUSTABLE ATTENUATOR



THIS IS A BIPOLARITY (+/−) VERSION OF THE ADJUSTABLE CLIPPER.

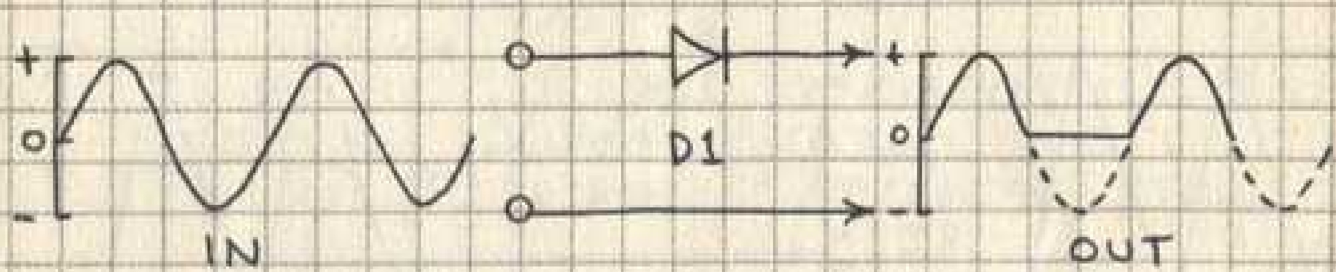
AUDIO LIMITER



USE TO LIMIT NOISE, POPS, AND STATIC.

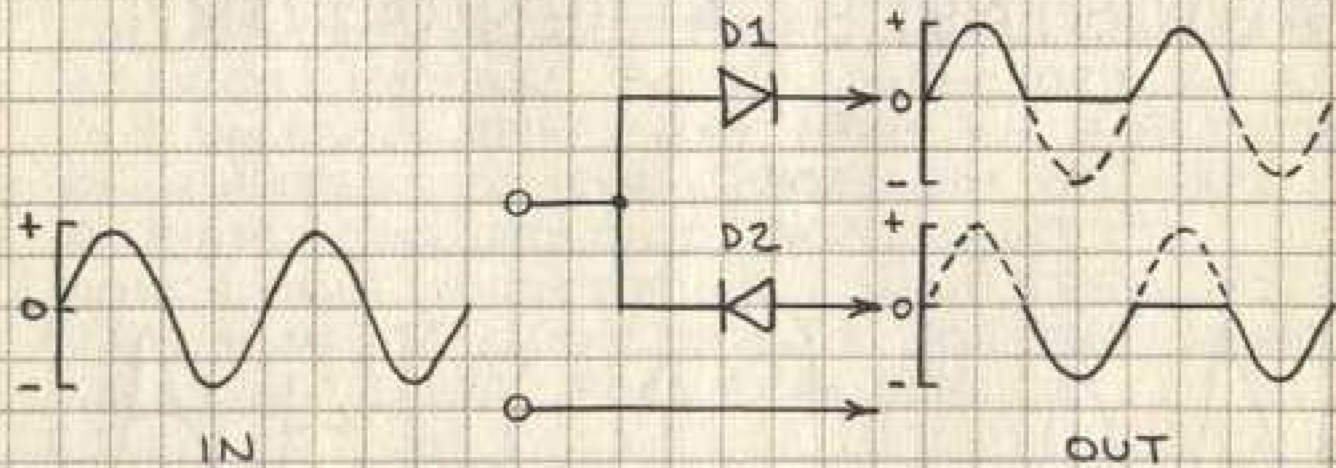
D1, D2 = 1N914

HALF-WAVE RECTIFIER



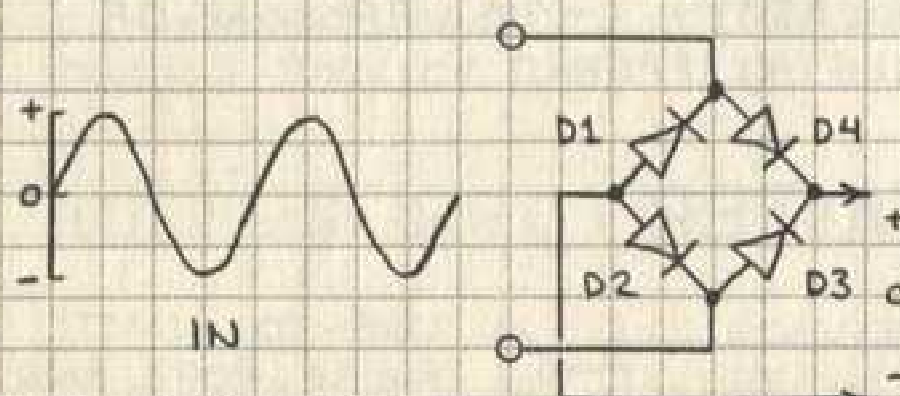
D1 IS ANY DIODE RATED FOR THE INPUT VOLTAGE. THIS CIRCUIT IS USED TO TRANSFORM AN AC WAVE INTO PULSATING DC AND TO DETECT MODULATED RADIO SIGNALS.

DUAL HALF-WAVE RECTIFIER



THIS CIRCUIT TRANSFORMS BOTH HALVES OF AN AC WAVE INTO PULSATING DC.

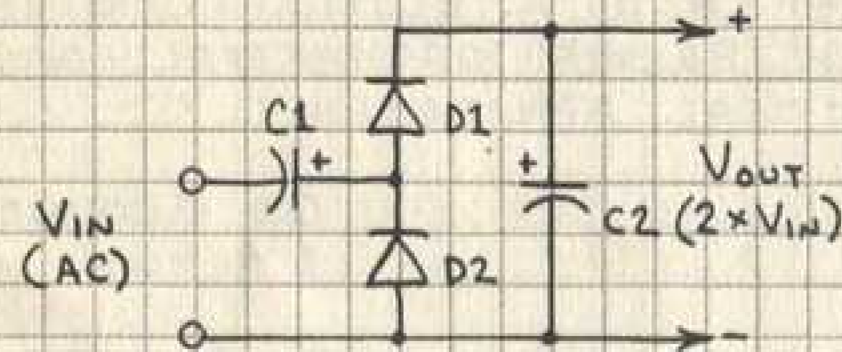
FULL-WAVE RECTIFIER



D1-D4 AVAILABLE AS MODULE.

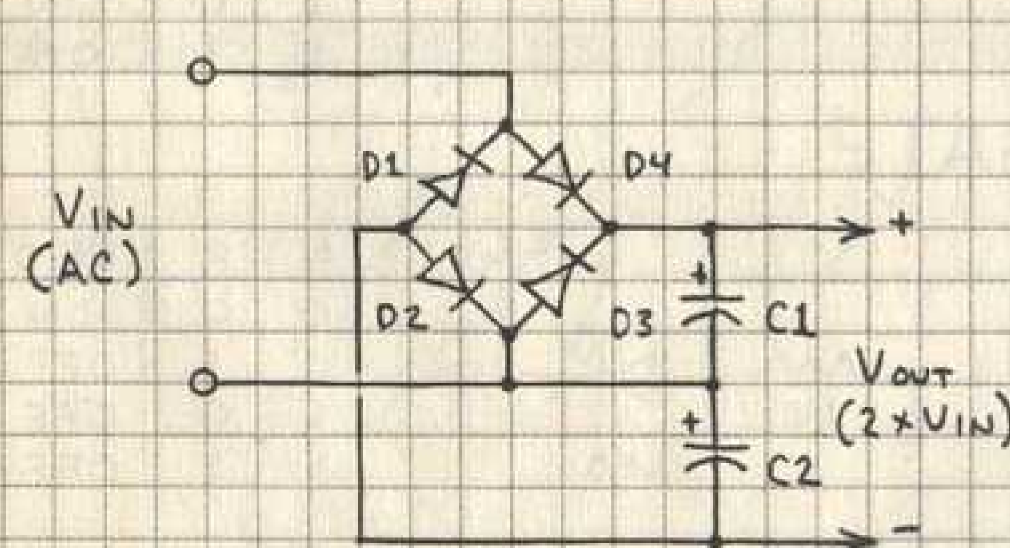
ALSO CALLED A BRIDGE RECTIFIER. USED TO TRANSFORM BOTH HALVES OF AC WAVE TO DC.

CASCADE VOLTAGE DOUBLER



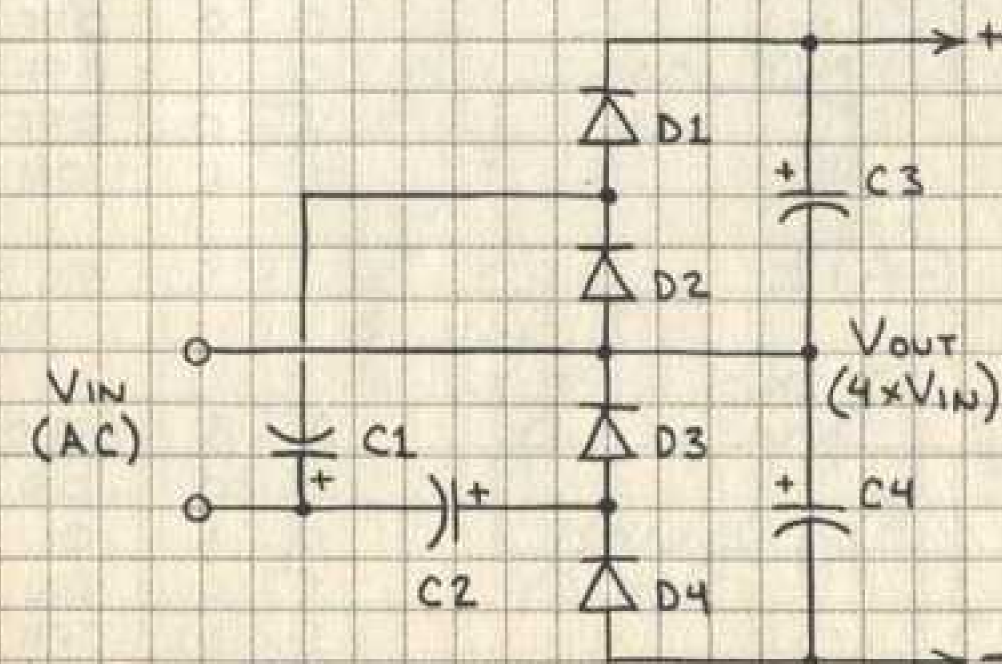
COMPONENTS SHOULD BE RATED AT $2 \times V_{IN}$. USE LARGE VALUE CAPACITORS TO REDUCE RIPPLE.

BRIDGE VOLTAGE DOUBLER



COMPONENTS SHOULD BE RATED AT $2 \times V_{IN}$. OK TO USE BRIDGE MODULE FOR D1, D2, D3 AND D4.

VOLTAGE QUADRUPLER



COMPONENTS SHOULD BE RATED AT $2 \times V_{IN}$. USE LARGE VALUE CAPACITORS TO REDUCE RIPPLE.

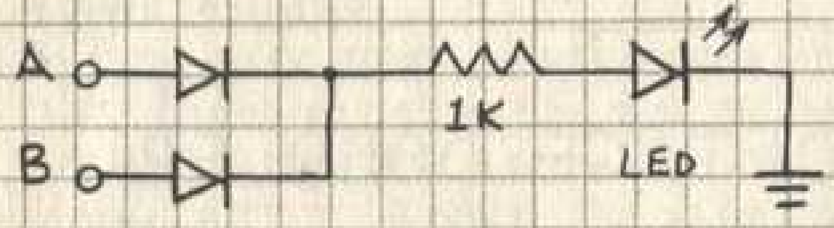
CAUTION: VOLTAGE MULTIPLICATION CIRCUITS CAN PRODUCE HIGH VOLTAGES. USE CARE!

DIODE LOGIC GATES

THESE SIMPLE LOGIC CIRCUITS CAN BE USED TO TEACH BASICS OF DIGITAL LOGIC AND IN PRACTICAL APPLICATIONS.

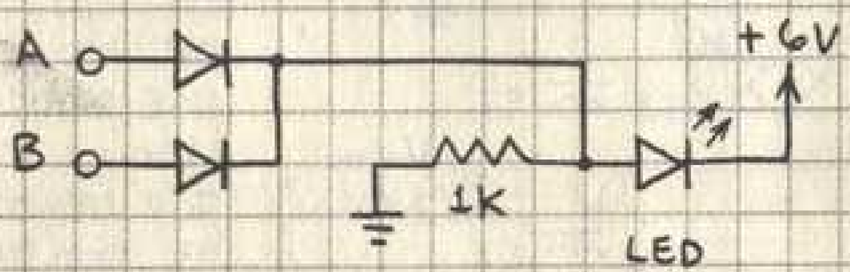
0 = GROUND
1 = +6V

OR GATE



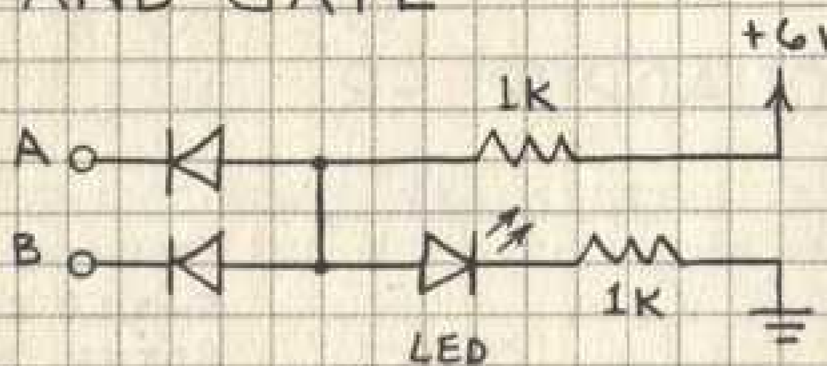
A	B	LED
0	0	OFF
0	1	ON
1	0	ON
1	1	ON

NOR GATE



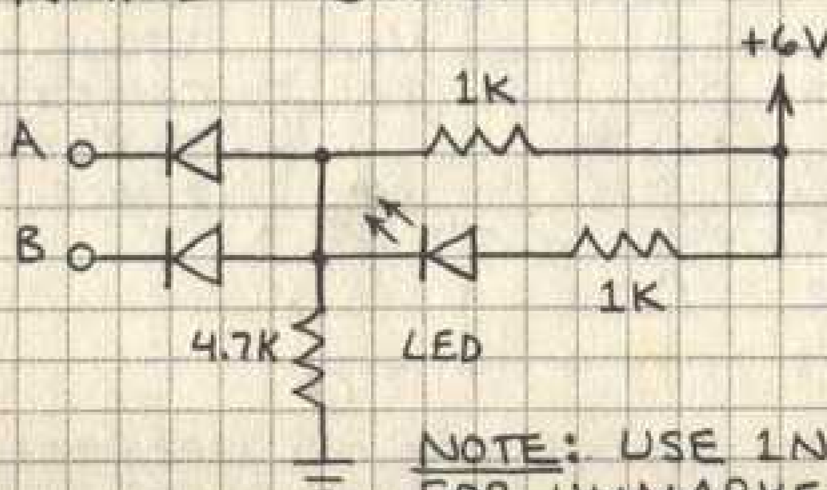
A	B	LED
0	0	ON
0	1	OFF
1	0	OFF
1	1	OFF

AND GATE



A	B	LED
0	0	OFF
0	1	OFF
1	0	OFF
1	1	ON

NAND GATE

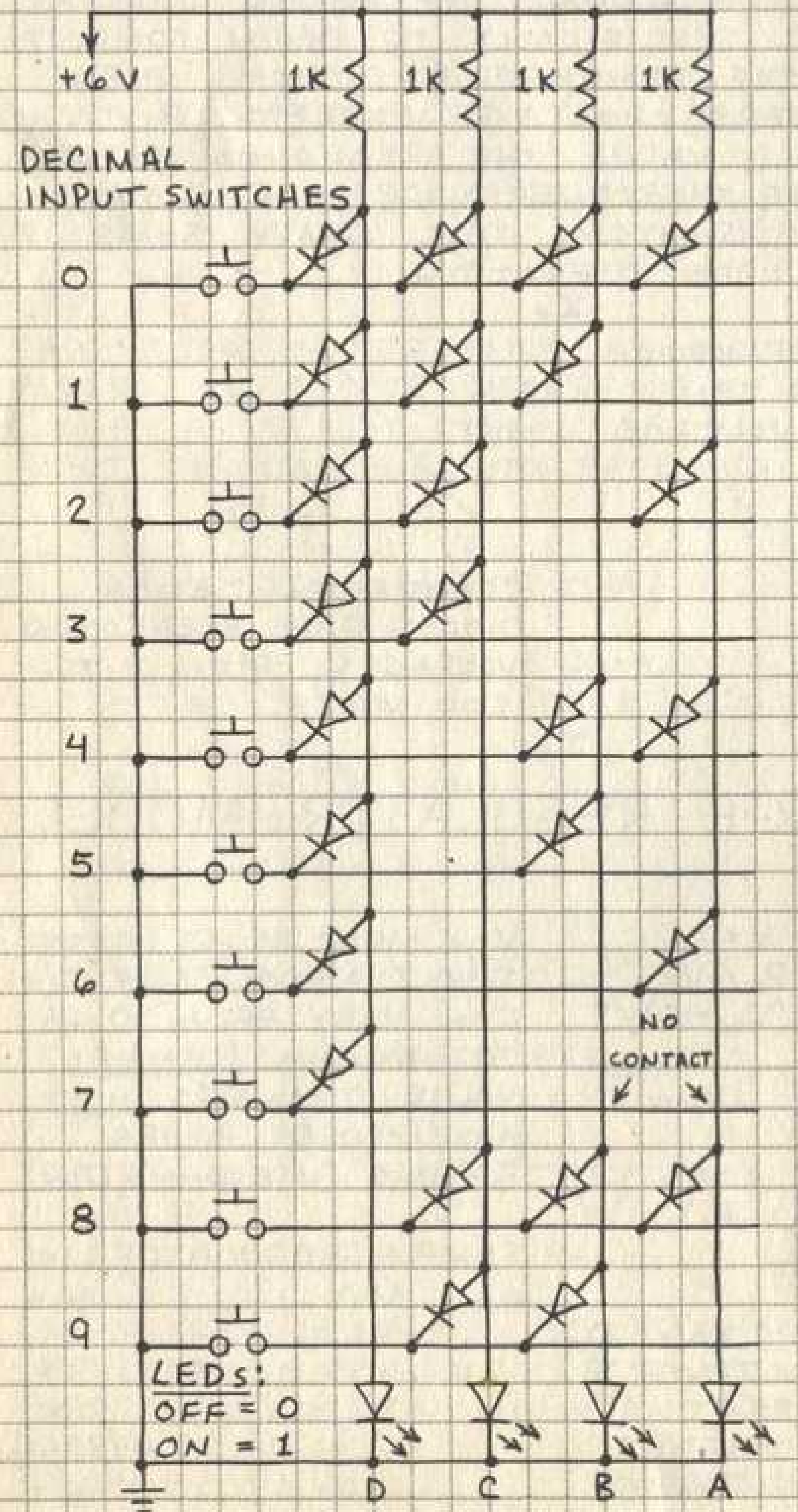


A	B	LED
0	0	ON
0	1	ON
1	0	ON
1	1	OFF

NOTE: USE 1N914 (OR SIMILAR) FOR UNMARKED INPUT DIODES.

DECIMAL-TO-BINARY ENCODER

THIS CIRCUIT IS A PROGRAMMABLE READ-ONLY MEMORY (PROM). USE 1N914 DIODES.



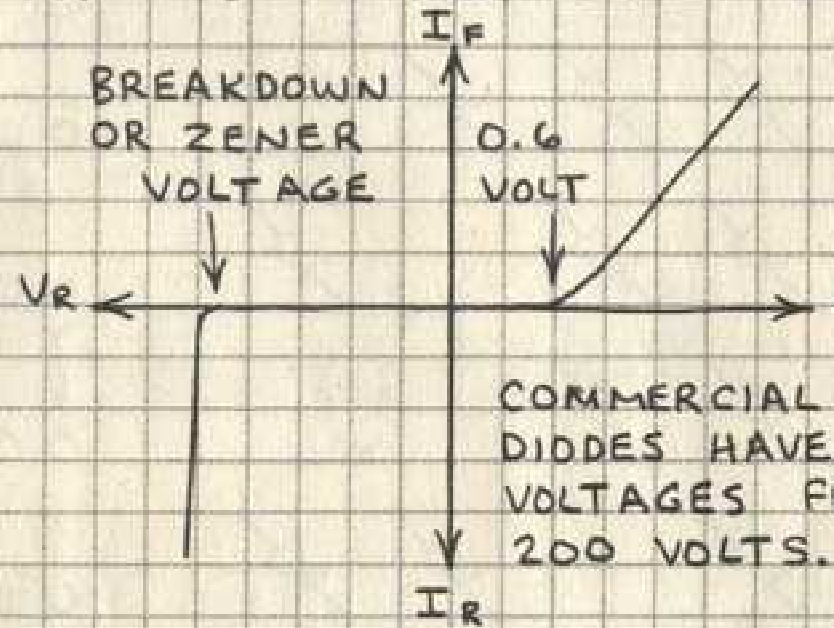
BINARY TRUTH TABLE

D	C	B	A
0	0	0	0
0	0	0	1
0	0	1	0
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0
0	1	1	1
1	0	0	0
1	0	0	1

BINARY READOUT LEDs

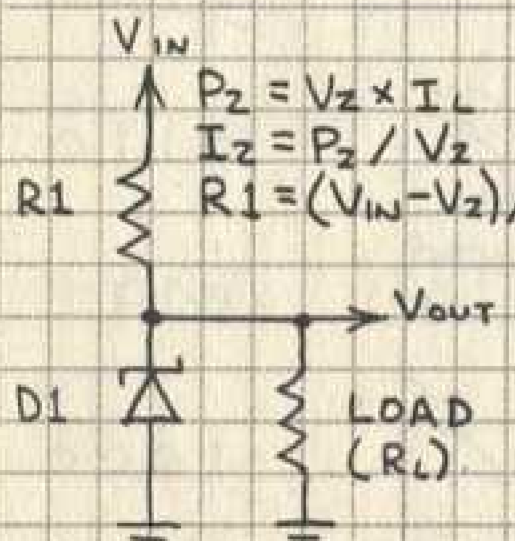
ZENER DIODES

NORMALLY A CURRENT DOES NOT FLOW THROUGH A DIODE CONNECTED IN THE REVERSE DIRECTION. THE ZENER DIODE IS DESIGNED SPECIFICALLY TO BEGIN CONDUCTING IN THE REVERSE DIRECTION WHEN THE REVERSE VOLTAGE EXCEEDS A THRESHOLD VALUE (THE BREAKDOWN VOLTAGE). THEREFORE THE ZENER DIODE IS A VOLTAGE-SENSITIVE SWITCH. THIS GRAPH SUMS UP ZENER DIODE OPERATION:



COMMERCIAL ZENER DIODES HAVE BREAKDOWN VOLTAGES FROM 2 TO 200 VOLTS.

VOLTAGE REGULATOR MODEL

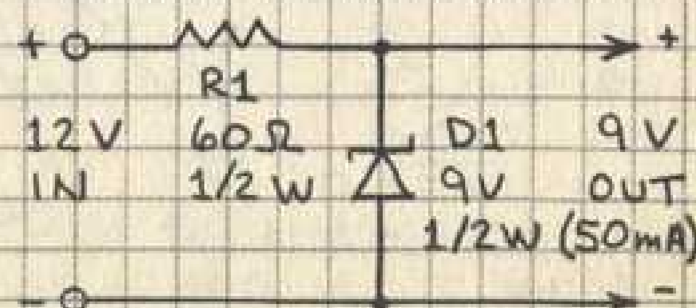


$P_Z = V_Z \times I_L$
$I_Z = P_Z / V_Z$
$R1 = (V_{IN} - V_Z)/I$

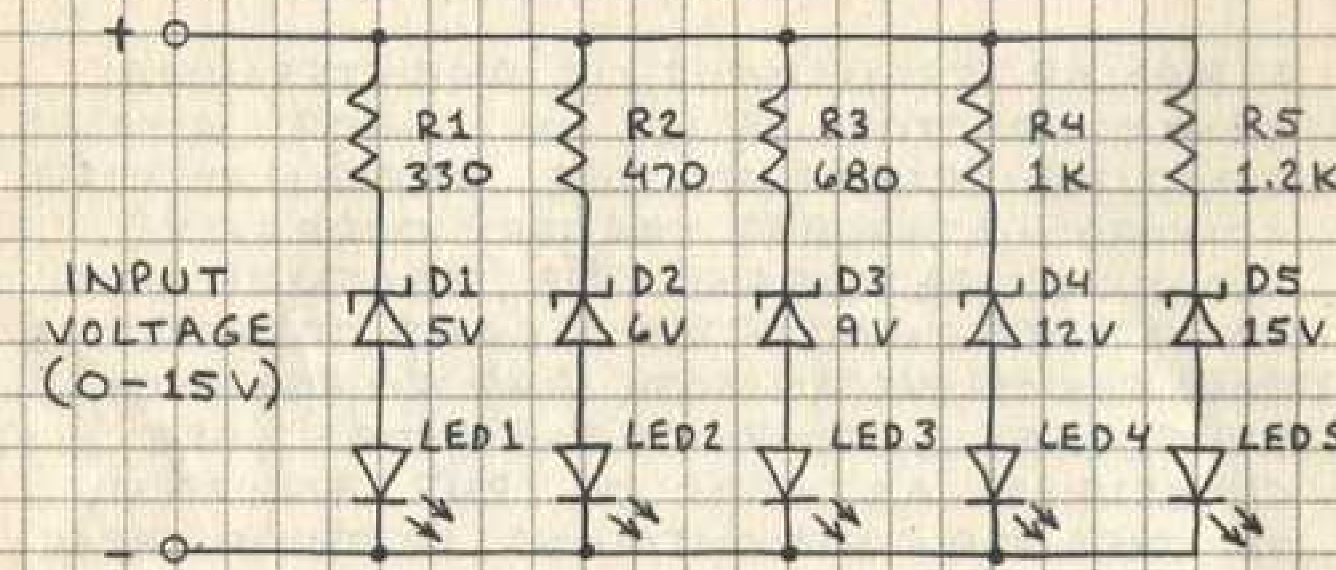
I_L = MAXIMUM LOAD I
I_Z = MAXIMUM ZENER I
I = R1 CURRENT
V_Z = ZENER VOLTAGE
P_Z = ZENER CURRENT

V_{IN} MUST BE AT LEAST 1 VOLT ABOVE V_{OUT}. I_L CAN VARY FROM 0mA TO MAXIMUM <u>PLANNED</u> VALUE. D1 AND R1 <u>MUST</u> HAVE PROPER POWER RATING (USE OHM'S LAW).

SAMPLE REGULATOR:

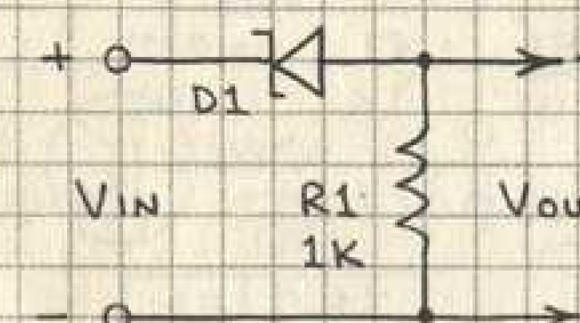


VOLTAGE INDICATOR



LEDs GLOW IN SEQUENCE AS INPUT VOLTAGE RISES. OK TO USE DIFFERENT ZENERS SO LONG AS SERIES RESISTOR LIMITS CURRENT THROUGH LED TO SAFE VALUE.

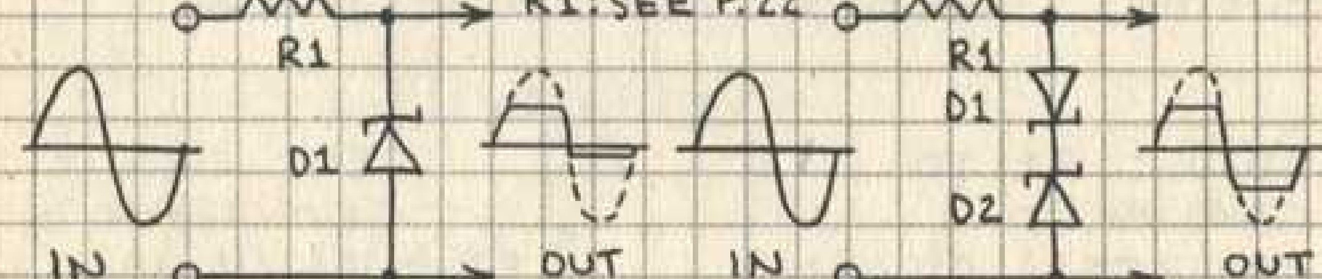
VOLTAGE SHIFTER



EXAMPLE (D1=6.2V):

V_{IN}	V_{OUT}
5	0
6	.36
9	3.17
12	6.37
15	9.27

WAVEFORM CLIPPERS



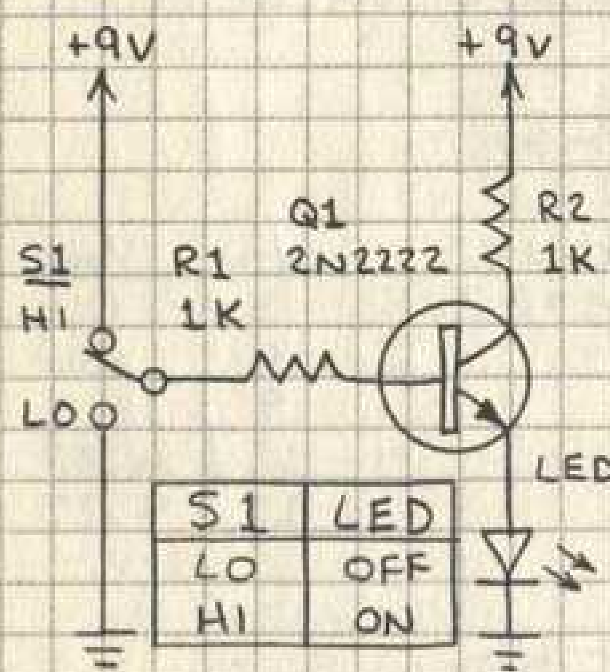
USE TO REDUCE LEVEL OF INCOMING SIGNAL. ALSO CONVERTS SINE WAVE TO NEAR SQUARE WAVE.

CLIPS <u>BOTH</u> HALVES OF WAVE (EQUALLY WHEN D1=D2). USE AS POP FILTER FOR SPEAKERS AND PHONES.

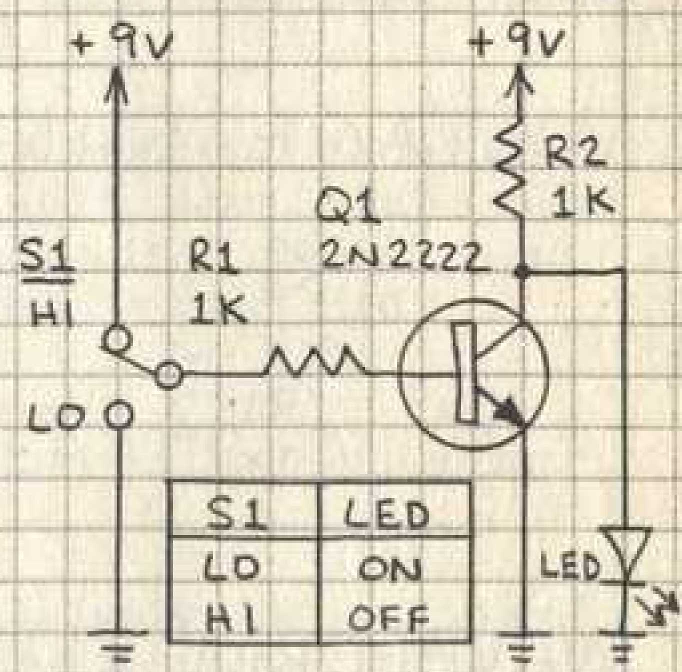
BIPOLAR TRANSISTORS

A BIPOLAR TRANSISTOR IS A 3-TERMINAL SEMICONDUCTOR DEVICE IN WHICH A SMALL CURRENT AT ONE TERMINAL CAN CONTROL A MUCH LARGER CURRENT FLOWING BETWEEN THE SECOND AND THIRD TERMINAL. THIS MEANS TRANSISTORS CAN FUNCTION AS BOTH AMPLIFIERS AND SWITCHES. BIPOLAR TRANSISTORS ARE CLASSIFIED AS NPN OR PNP ACCORDING TO THE DOPING CONTAINED IN THEIR THREE REGIONS.

BASIC TRANSISTOR SWITCHES



S1	LED
LO	OFF
HI	ON

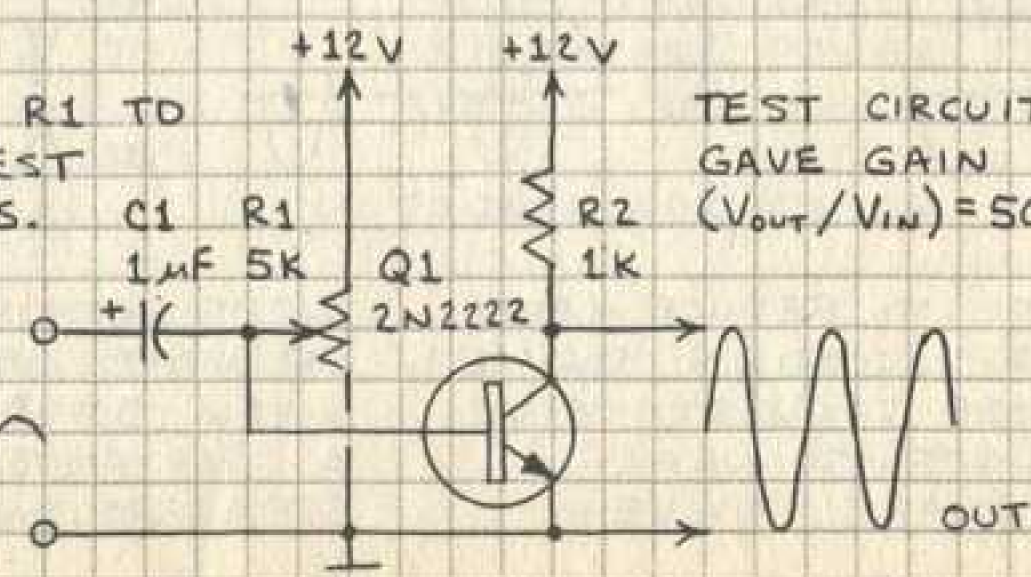


S1	LED
LO	ON
HI	OFF

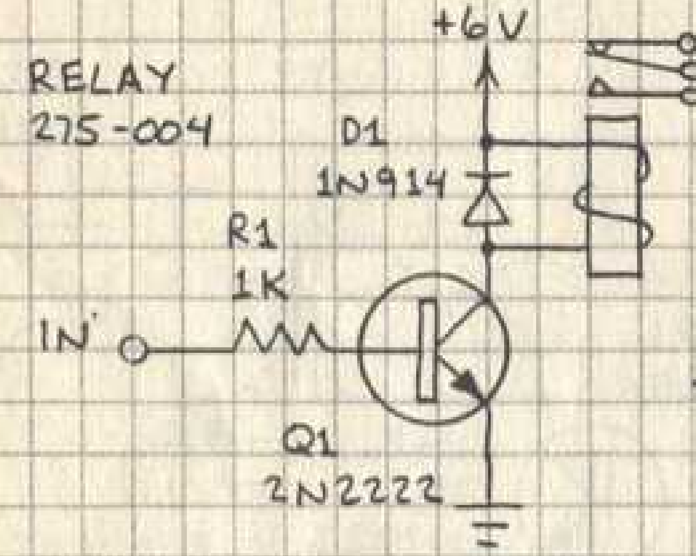
BASIC TRANSISTOR AMPLIFIER

ADJUST R1 TO GIVE BEST RESULTS.

TEST CIRCUIT GAVE GAIN $(V_{OUT}/V_{IN})=50$.

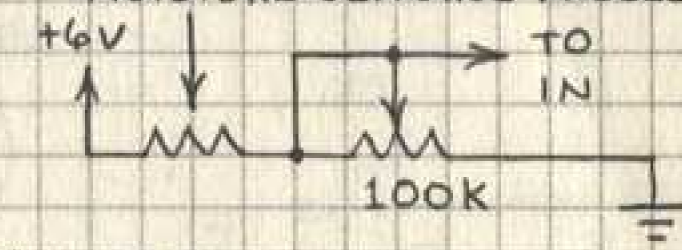


RELAY DRIVER

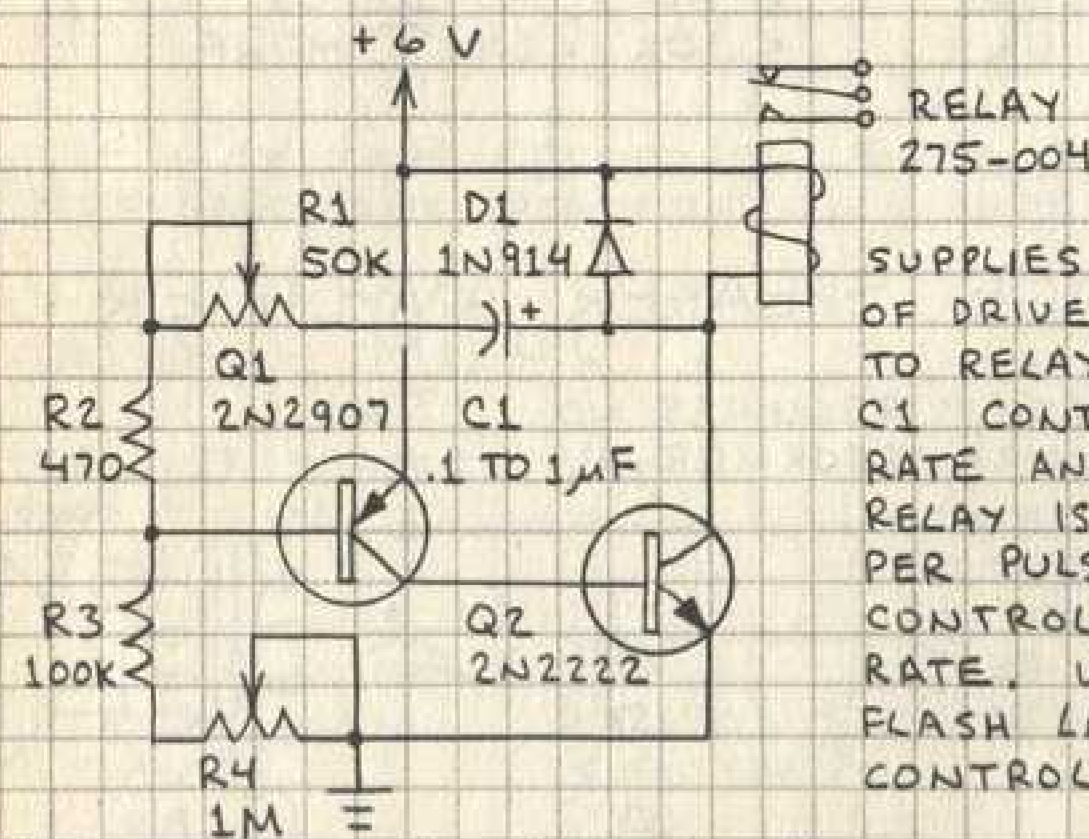


RELAY PULLS IN WHEN INPUT IS <u>POSITIVE</u>.
APPLICATION:

RESISTIVE SENSOR OR MOISTURE-SENSING PROBES

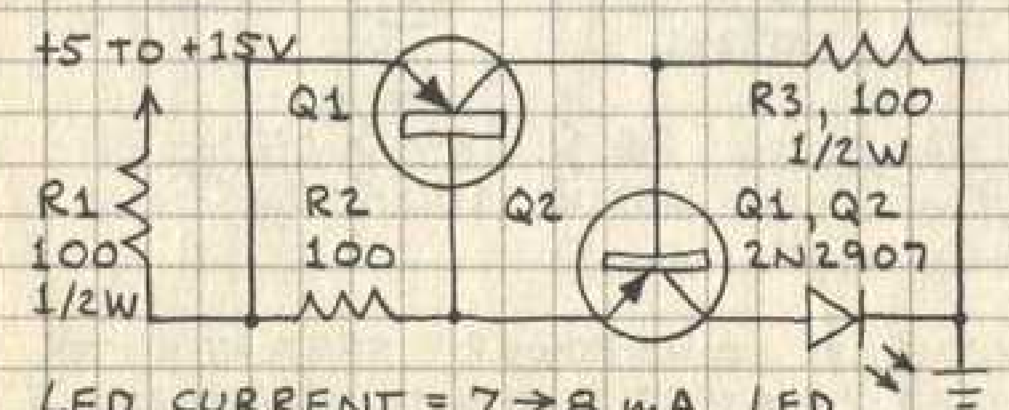


RELAY CONTROLLER



SUPPLIES SEQUENCE OF DRIVE PULSES TO RELAY. R1 AND C1 CONTROL PULSE RATE AND TIME RELAY IS CLOSED PER PULSE. R4 CONTROLS PULSE RATE. USE TO FLASH LAMPS AND CONTROL MOTORS.

LED REGULATOR

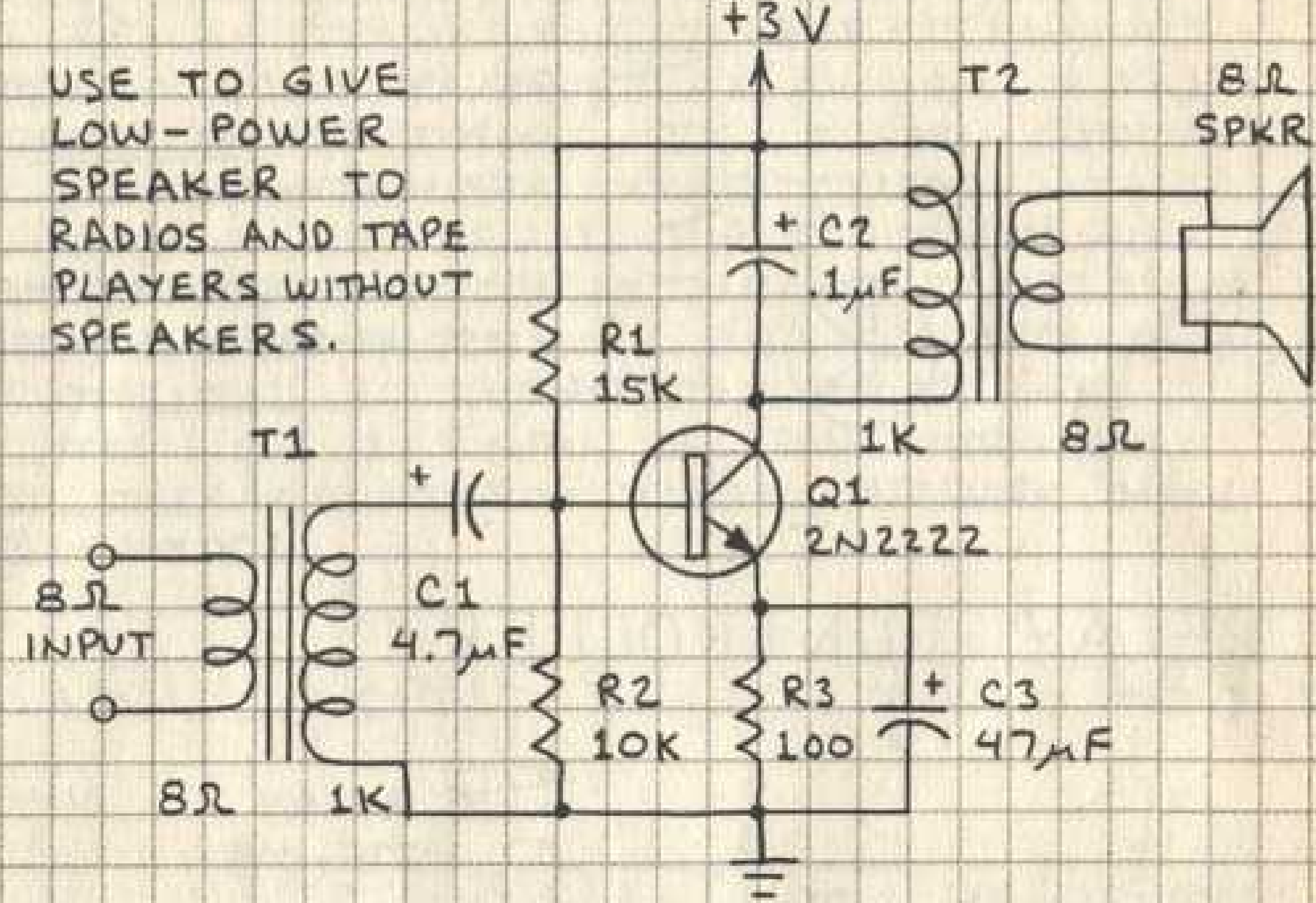


SUPPLIES CONSTANT CURRENT TO LED AS SUPPLY VOLTAGE CHANGES.

LED CURRENT = 7 → 8 mA.

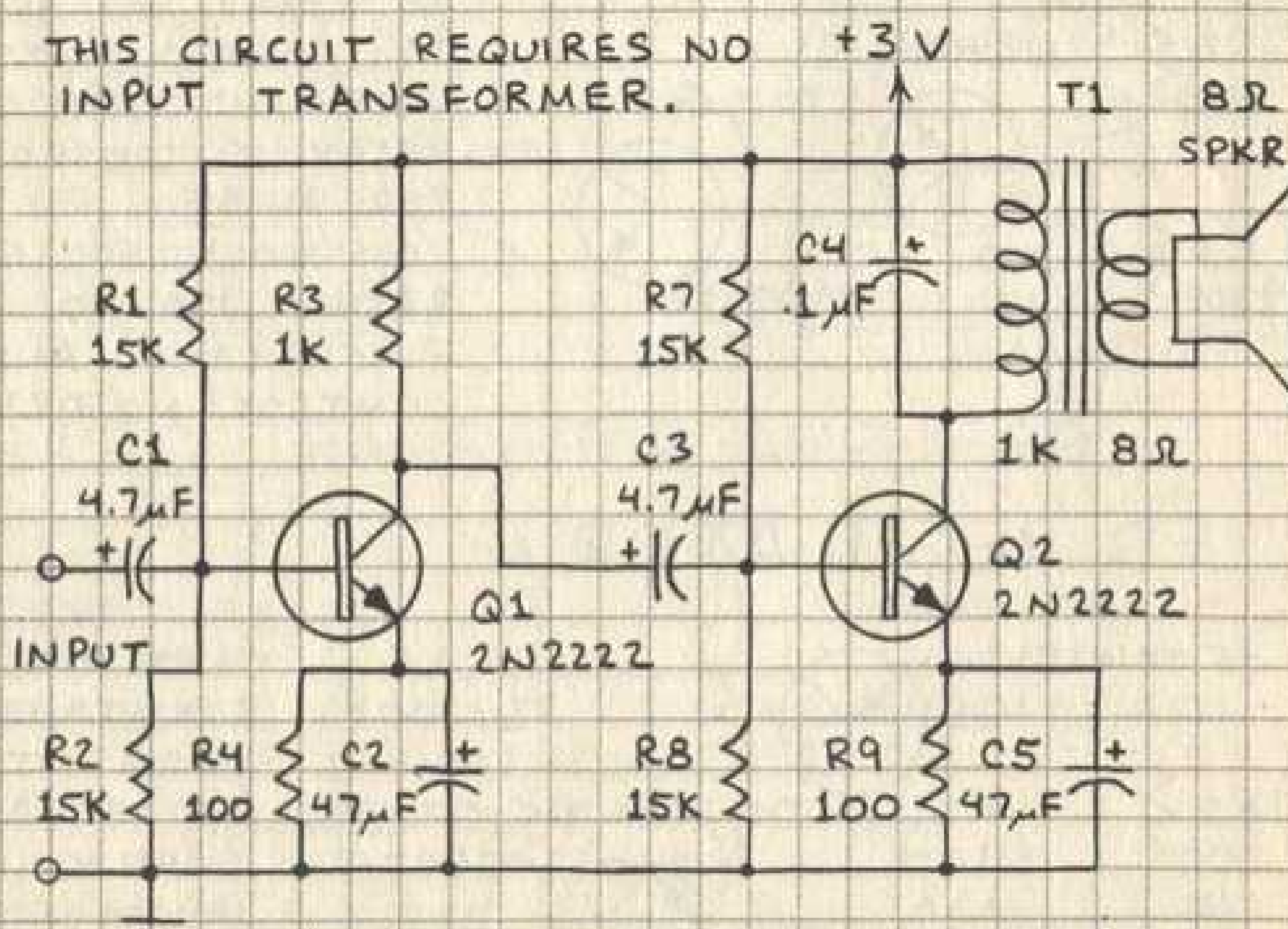
3-VOLT SPEAKER AMPLIFIER

USE TO GIVE LOW-POWER SPEAKER TO RADIOS AND TAPE PLAYERS WITHOUT SPEAKERS.



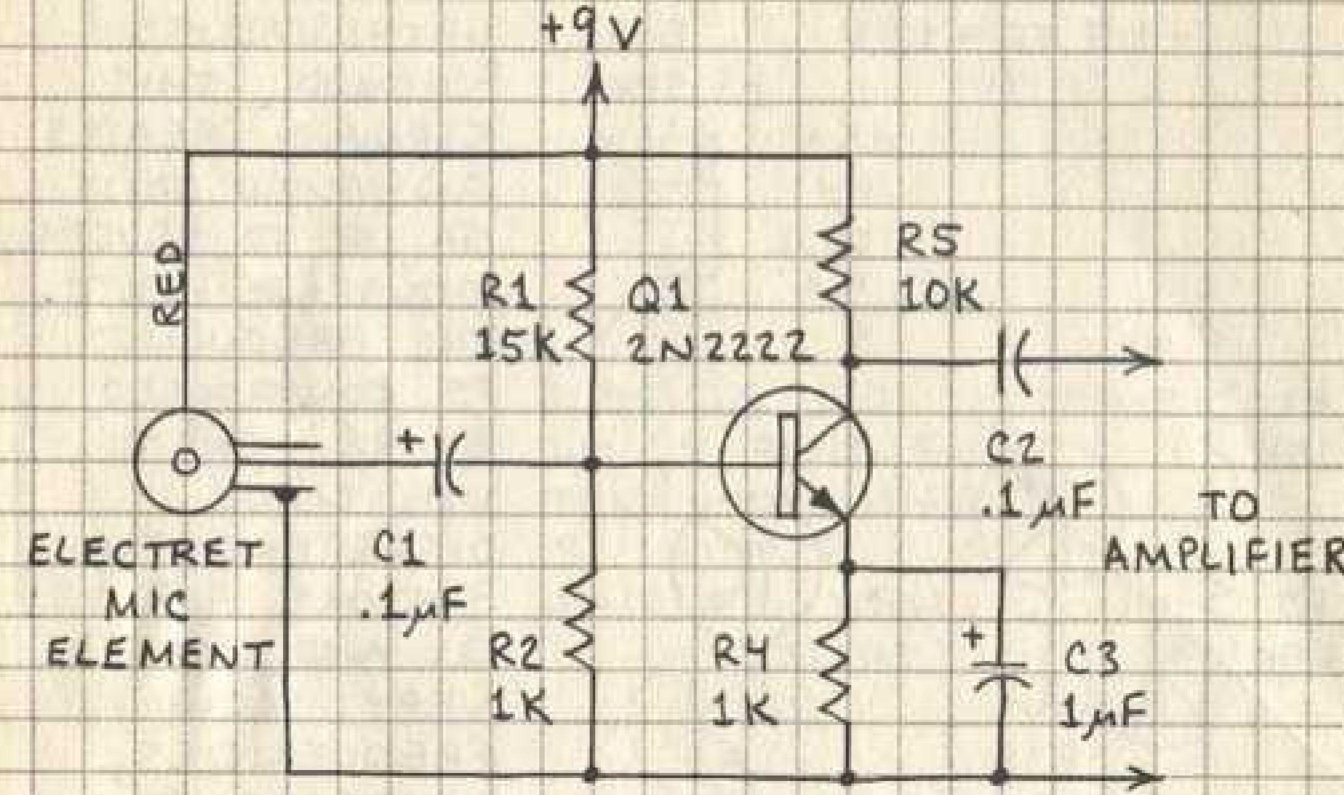
2-STAGE SPEAKER AMPLIFIER

THIS CIRCUIT REQUIRES NO INPUT TRANSFORMER.



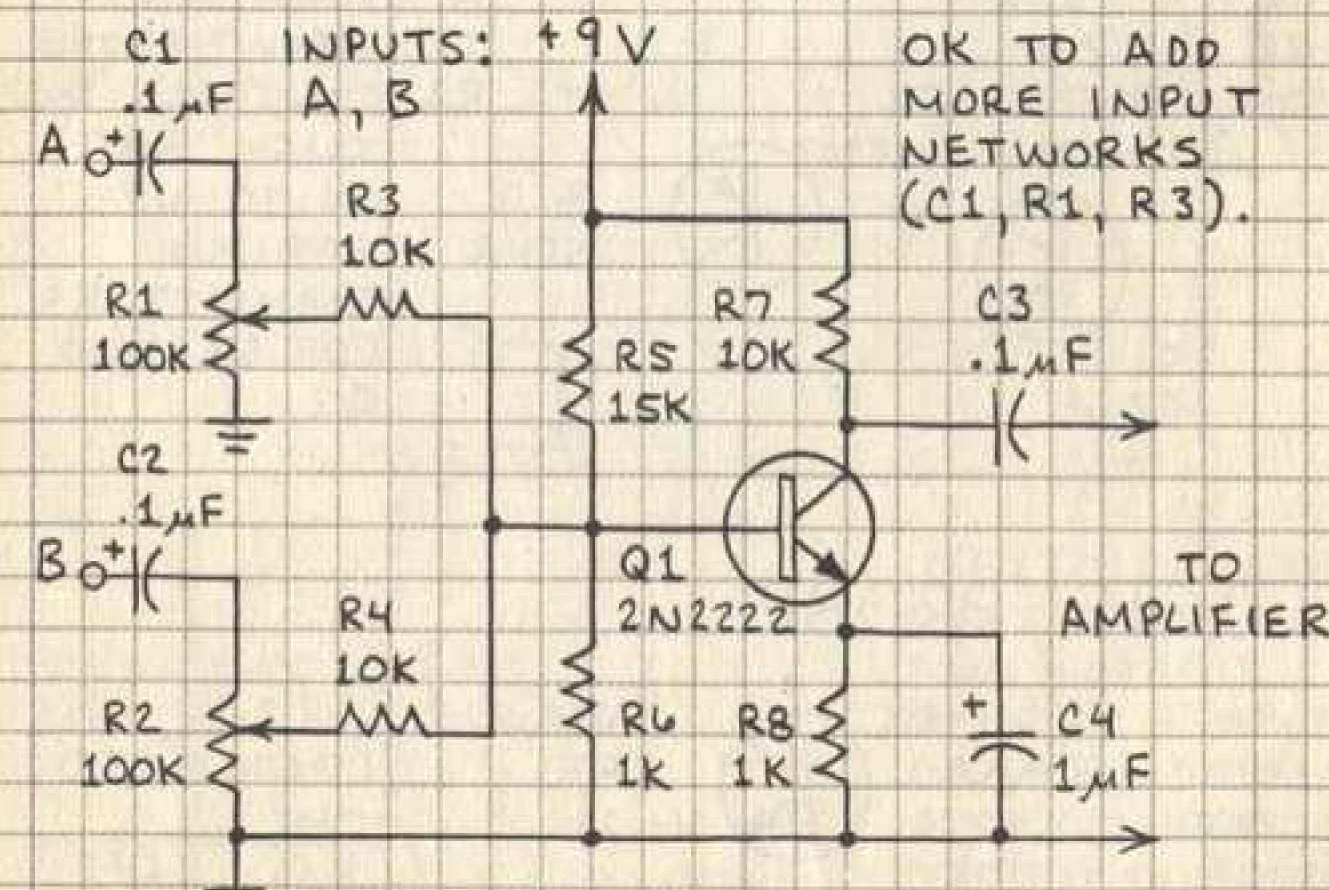
USE TO GIVE LOW-POWER SPEAKER TO RADIOS AND TAPE PLAYERS WITHOUT SPEAKERS.

MICROPHONE PREAMPLIFIER



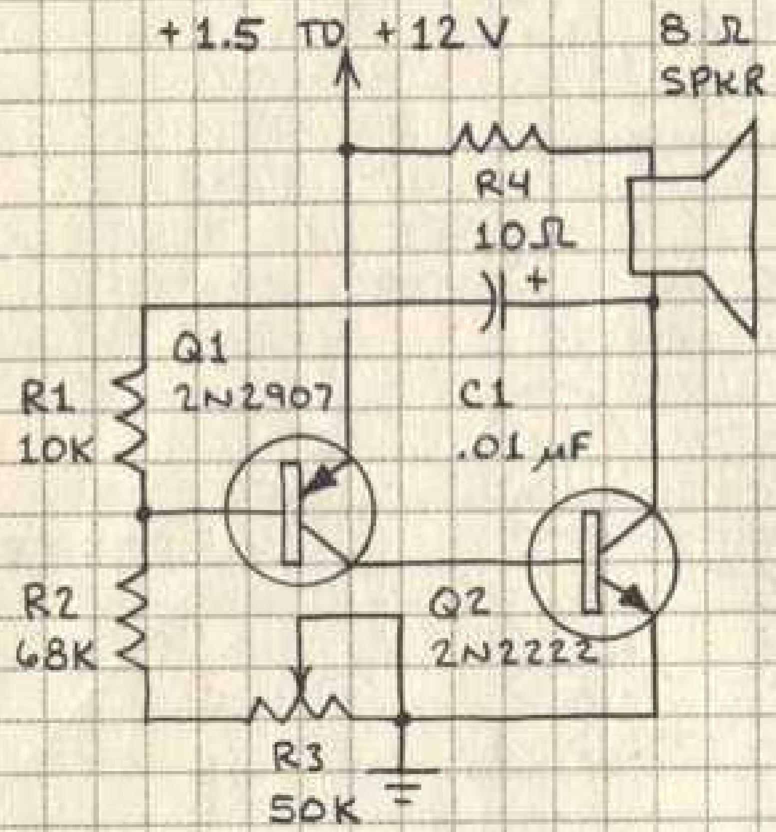
USE WITH TAPE RECORDERS, PUBLIC ADDRESS SYSTEMS AND PORTABLE AMPLIFIERS.

AUDIO MIXER



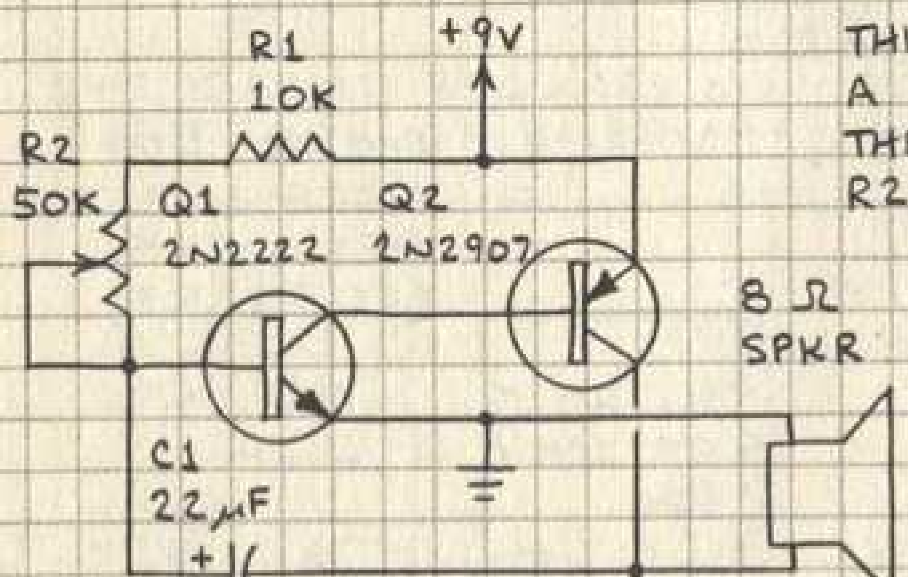
USE TO COMBINE SIGNALS FROM TWO (OR MORE) AMPLIFIERS, MICROPHONES, ETC.

AUDIO OSCILLATOR



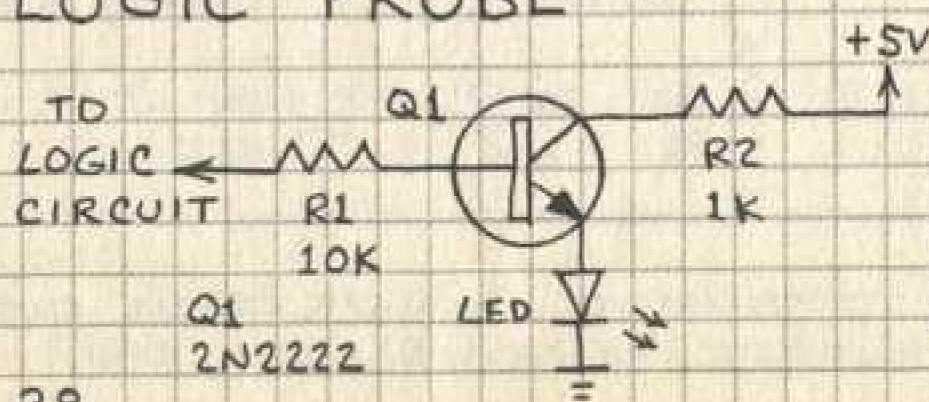
WITH VALUES SHOWN, THIS CIRCUIT CREATES AN AUDIO TONE OF UP TO SEVERAL THOUSAND HERTZ. THE FREQUENCY IS CONTROLLED BY R3. OK TO USE MANY DIFFERENT TRANSISTORS FOR Q1 AND Q2. FOR VERY SLOW FREQUENCIES, INCREASE C1.

METRONOME



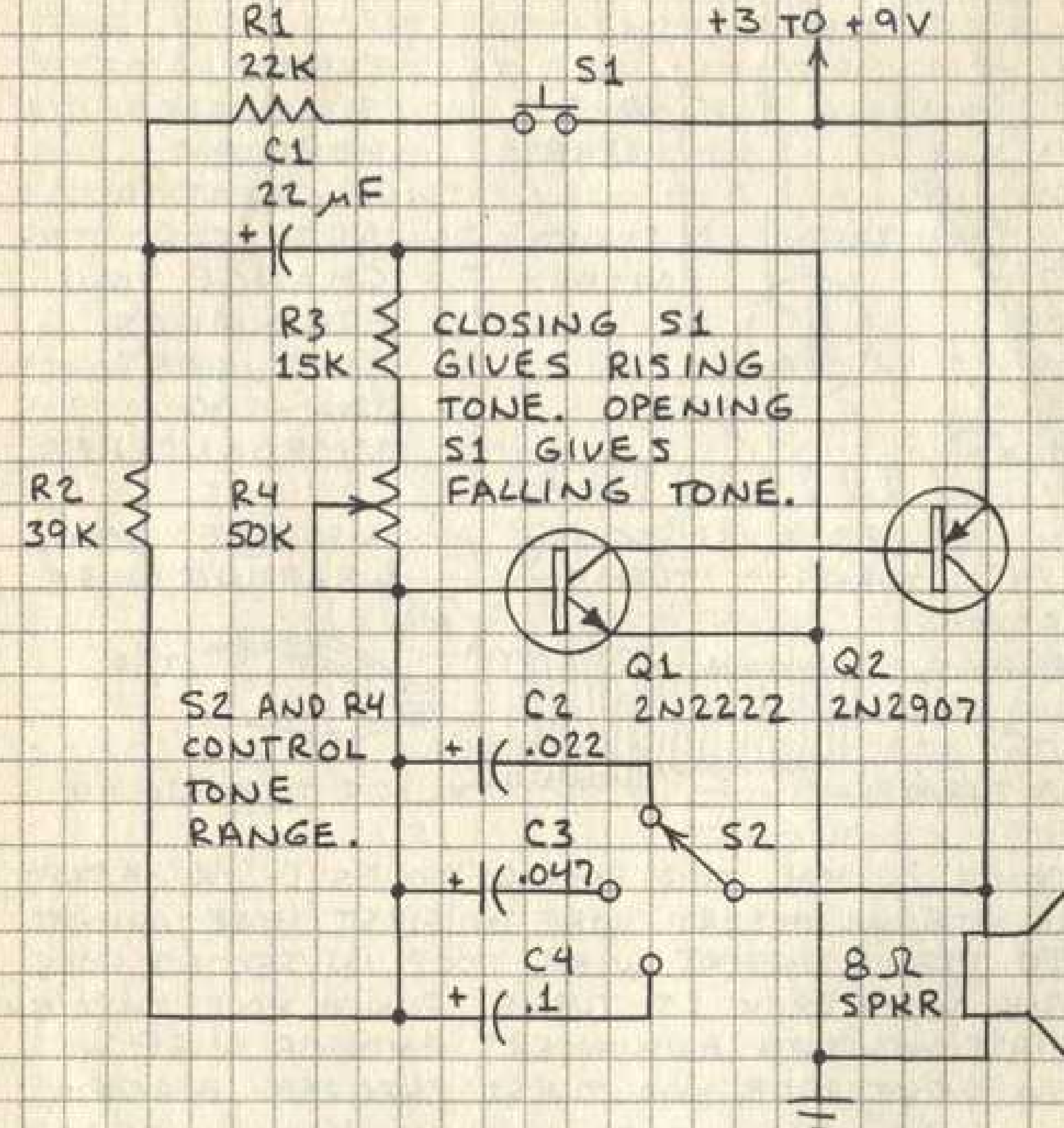
THIS CIRCUIT IS A VARIATION OF THE CIRCUIT ABOVE. R2 CONTROLS THE "CLICK" RATE. OK TO USE VARIOUS TRANSISTORS FOR Q1 AND Q2.

LOGIC PROBE



LOGIC IN	LED
LO	OFF
HI	ON

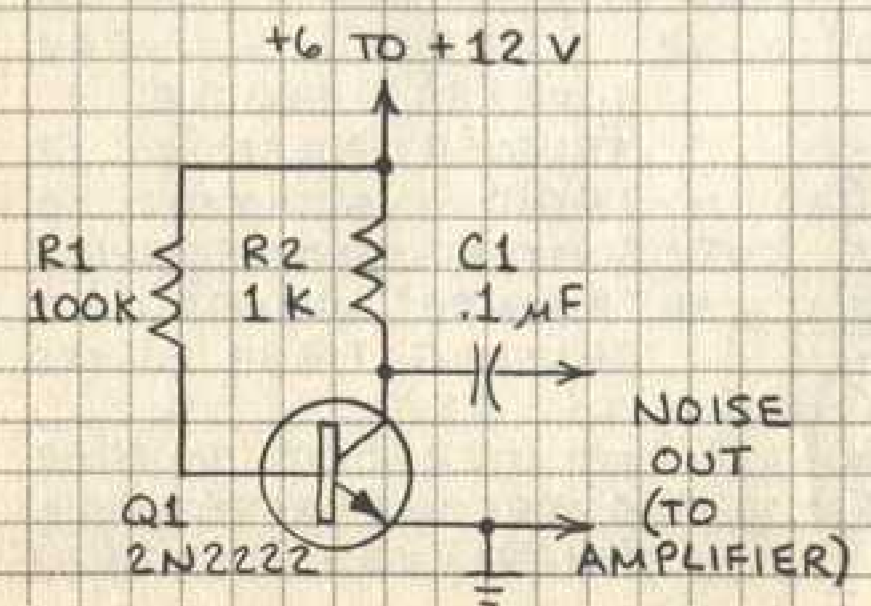
ADJUSTABLE SIREN



CLOSING S1 GIVES RISING TONE. OPENING S1 GIVES FALLING TONE.

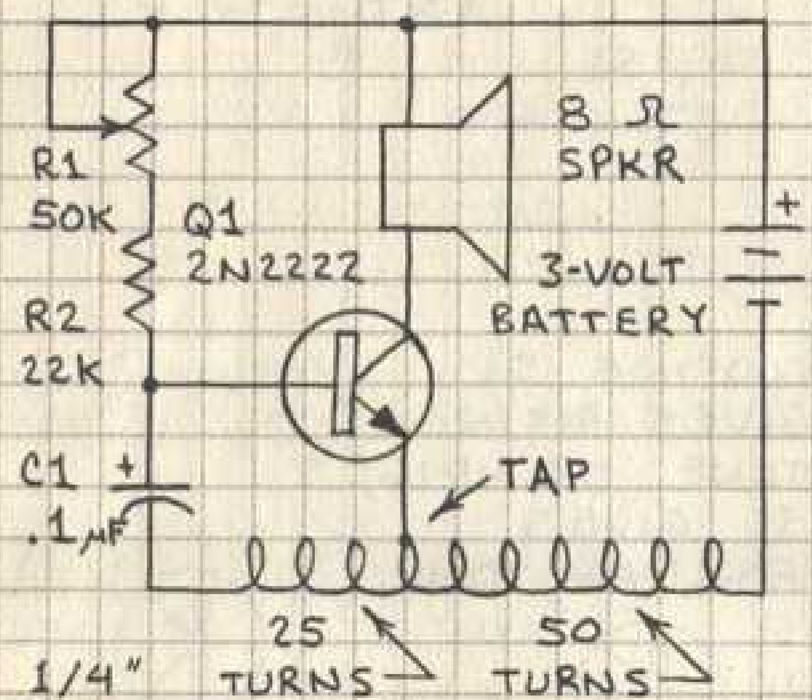
S2 AND R4 CONTROL TONE RANGE.

AUDIO NOISE GENERATOR

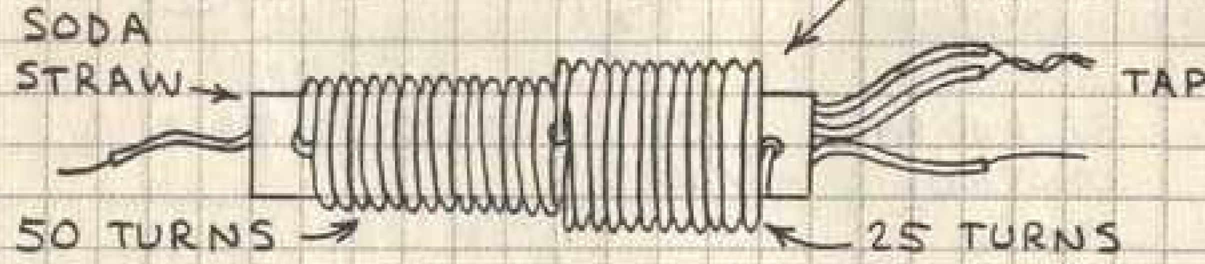


USE TO CREATE FUZZ SOUND AND OTHER SPECIAL EFFECTS OR AS NOISE SOURCE FOR TESTING ROOM ACOUSTICS WITH SOUND METER.

1-TRANSISTOR OSCILLATOR

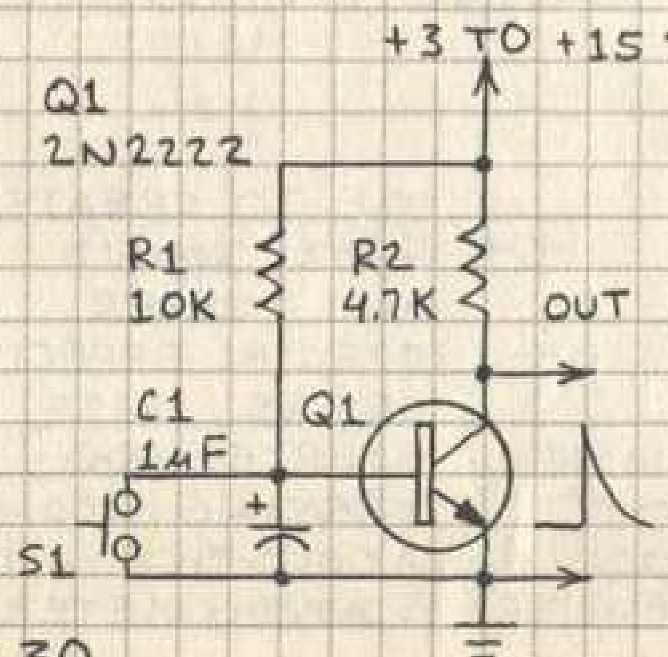


THIS IS A SIMPLIFIED HARTLEY OSCILLATOR. ADJUST R1 TO CHANGE TONE FREQUENCY. CONSUMES ONLY 100 - 200 MICROAMPERES.



COIL: PUNCH TWO SMALL HOLES 1-1/8" APART IN STRAW. INSERT WIRE IN FIRST HOLE, WIND 50 TURNS, INSERT WIRE LOOP IN SECOND HOLE, AND WIND BACK 25 TURNS. PUNCH HOLE THROUGH FIRST WINDING AND INSERT END OF WIRE. TAP: CUT LOOP AND TWIST EXPOSED WIRES.

SWITCH DEBOUNCER

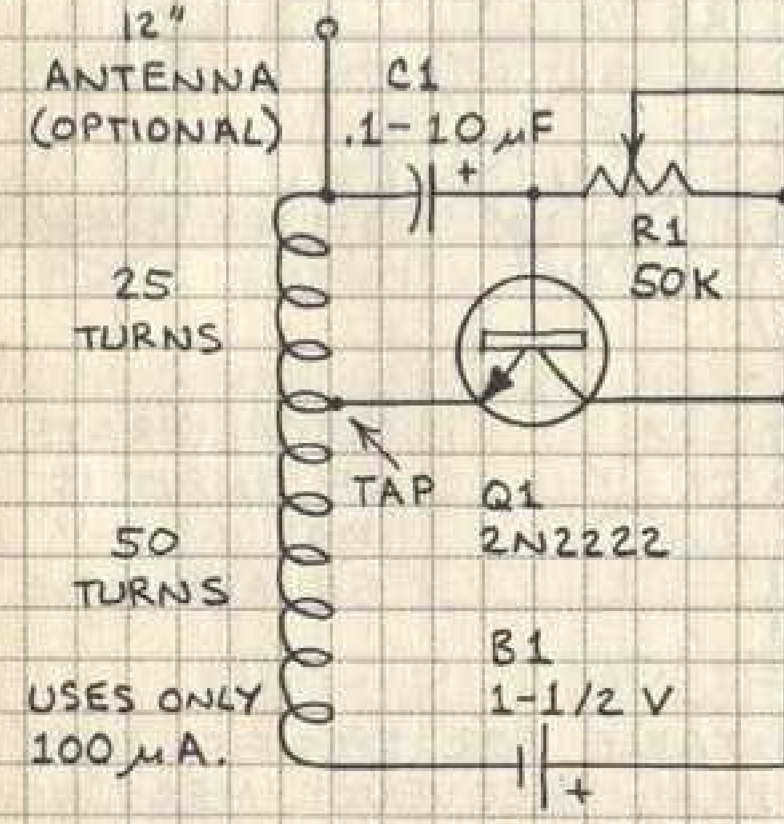


SUPPLIES SINGLE TRIGGER PULSE TO LOGIC CIRCUITS. SWITCH ALONE WILL "BOUNCE" WHEN CLOSED, CAUSING FALSE PULSES.

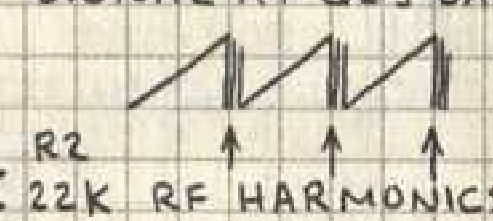
TO LOCK OUT S1 FOR A SECOND AFTER A PULSE, LET C1 = 220 µF.

MINIATURE RF TRANSMITTER

THIS CIRCUIT IS PATTERNED AFTER A PILL-SIZED BIOTELEMETRY TRANSMITTER FIRST DEVELOPED BY DR. R. STEWART MACKAY AND OTHER MEDICAL RESEARCHERS IN THE LATE 1950'S. THIS TRANSMITTER REMAINS ONE OF THE SMALLEST EVER DEVELOPED.



SIGNAL AT Q1'S BASE:



SENDS SIGNAL TO AM OR SW RADIO A FEW FEET AWAY. R1 (AND R2) CONTROLS SIGNAL FREQUENCY. OK TO USE CdS CELL OR THERMISTOR FOR R1 / R2.

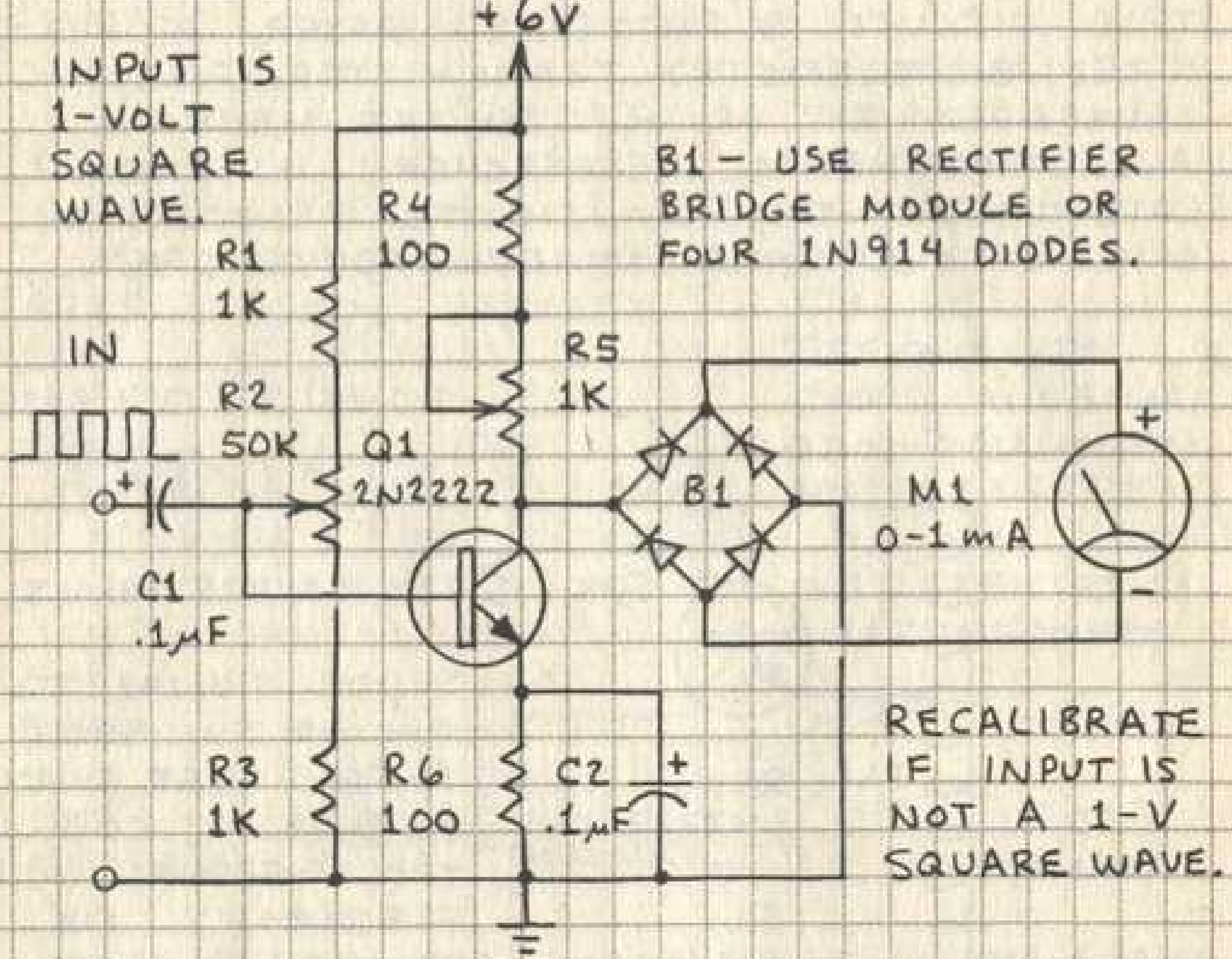
COIL: USE THE COIL SHOWN ON THE FACING PAGE OR MAKE A MUCH SMALLER VERSION WITH A 1/2" LENGTH OF SODA STRAW AND NO. 30 MAGNET WIRE. BURN THE VARNISH FROM THE LAST 1/4" OF THE COIL'S LEADS (USE A MATCH). THEN LIGHTLY BUFF THE CHARRED VARNISH WITH FINE SAND PAPER.

B1: USE A PENLIGHT CELL OR A MERCURY OR SILVER OXIDE BUTTON CELL. WARNING: NEVER ATTEMPT TO SOLDER LEADS TO MINIATURE POWER CELLS. THEY WILL EXPLODE.

C1: 0.1 µF GIVES AUDIO TONE; 10 µF GIVES AUDIBLE CLICKS. INSERT FERRITE CORE OR STEEL NAIL IN COIL TO ALTER THE SIGNAL. USE MINIATURE ELECTROLYTIC CAPACITOR.

FREQUENCY METER

INPUT IS 1-VOLT SQUARE WAVE.



B1 - USE RECTIFIER BRIDGE MODULE OR FOUR 1N914 DIODES.

RECALIBRATE IF INPUT IS NOT A 1-V SQUARE WAVE.

THIS CIRCUIT IS SUITABLE FOR SPECIFIC ROLES RATHER THAN GENERAL FREQUENCY MEASUREMENTS. TO CALIBRATE FOR 0-1 KHz RANGE:

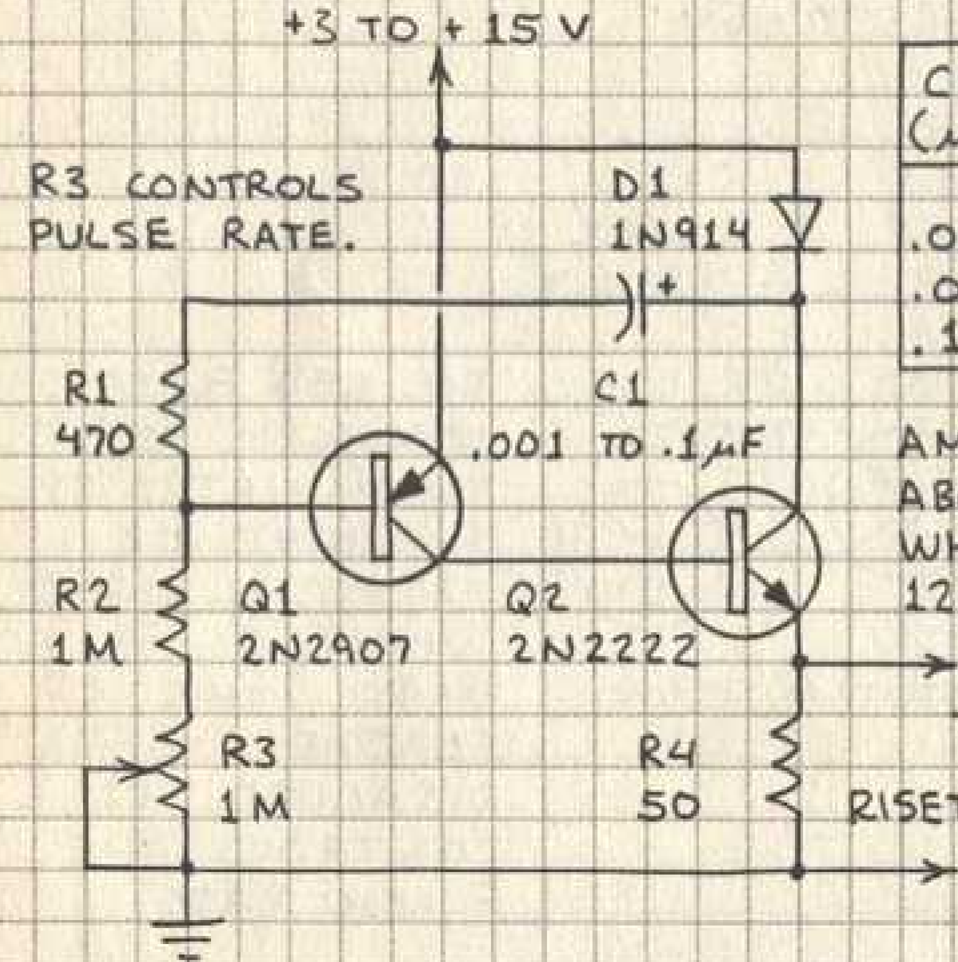
1. SET R2 AND R5 AT MID POINTS.
2. APPLY 1 KHz, 1 VOLT SQUARE WAVE AT INPUT.
3. ADJUST R2 UNTIL M1 = 1 mA.
4. REMOVE 1 KHz SIGNAL.
5. ADJUST R3 UNTIL M1 = 0.
6. REAPPLY 1 KHz SIGNAL.
7. ADJUST R2 UNTIL M1 = 1 mA.

TYPICAL RESULTS:

SIGNAL (Hz)	M1 (mA)
0	.02
100	.1
200	.24
300	.34
400	.44
500	.55
600	.65
700	.77
800	.85
900	.95
1000	1.00

PULSE GENERATOR

R3 CONTROLS PULSE RATE.

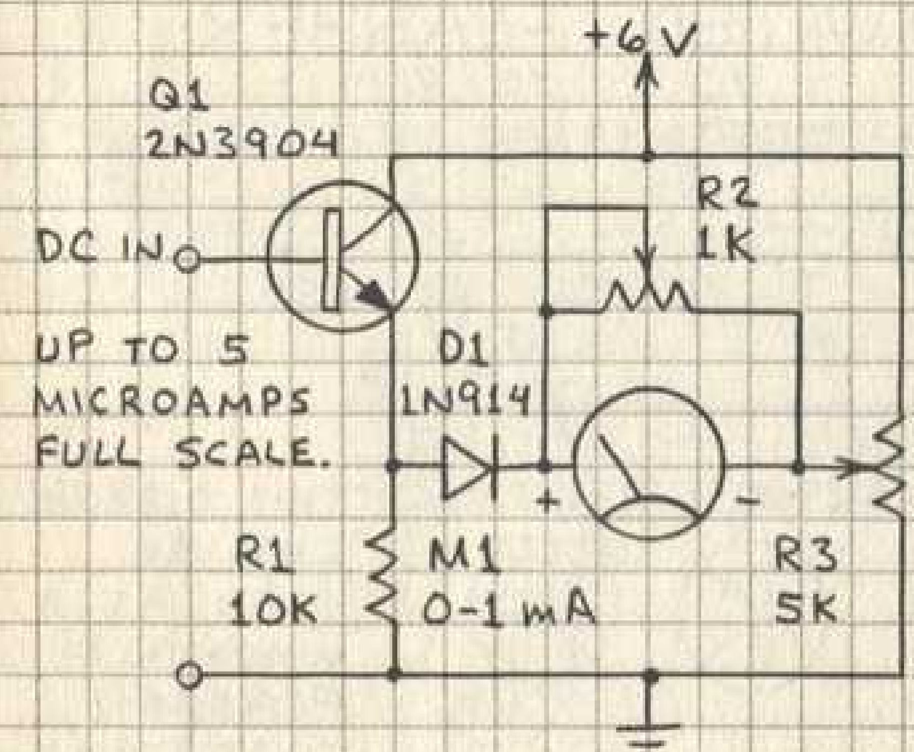


C1 (μF)	PULSE DURATION
.001	5 μSEC
.01	22 μSEC
.1	200 μSEC

AMPLITUDE IS ABOUT 10 VOLTS WHEN SUPPLY IS 12.5 VOLTS.

RISETIME = 100 nsec

DC METER AMPLIFIER

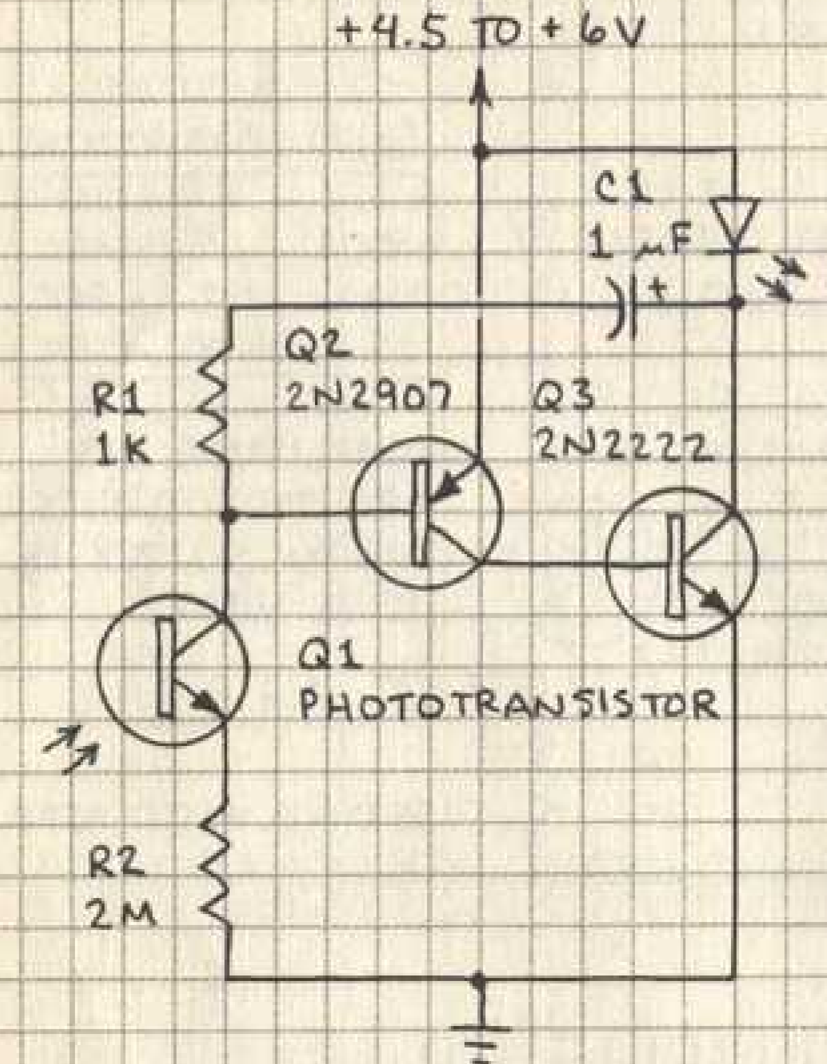


UP TO 5 MICROAMPS FULL SCALE.

TO CALIBRATE, FIRST CONNECT INPUT TO +6V THROUGH A 1M POT AND A DIGITAL MULTIMETER SET TO READ CURRENT IN MILLIAMPERES. THEN SET R2 AT ITS MID POINT. NEXT:

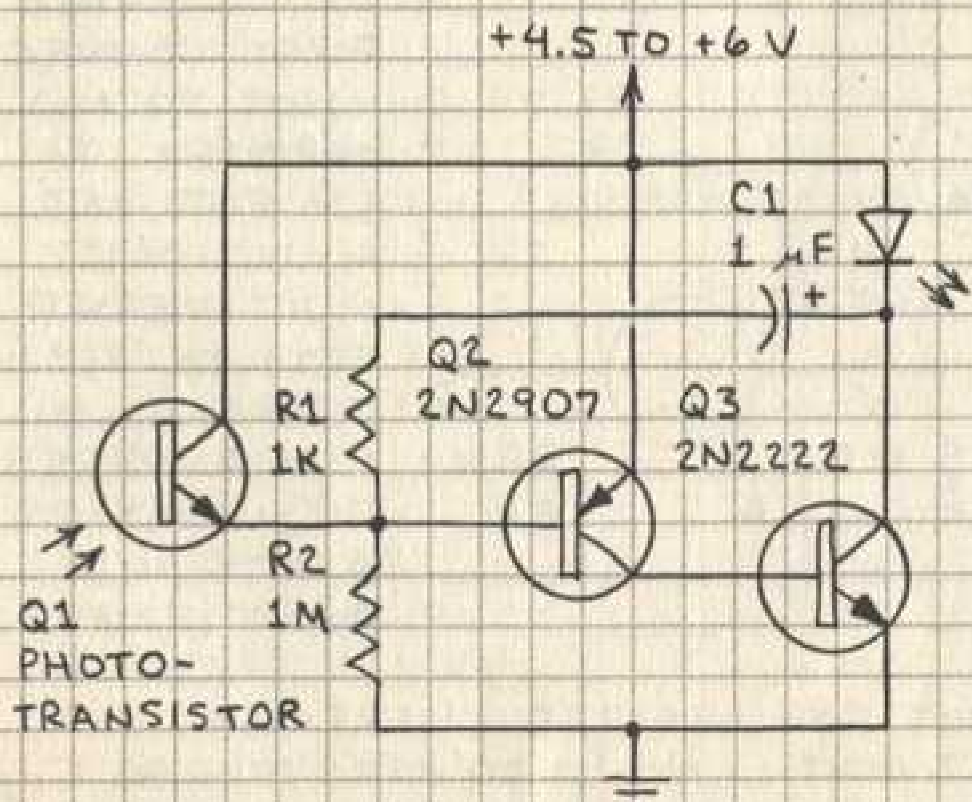
1. SET 1M POT FOR DESIRED CURRENT.
2. ADJUST R3 UNTIL M1 INDICATES 1 mA.
3. REPEAT STEPS 1 AND 2.
4. ADJUST R2 UNTIL M1 INDICATES 1 mA.

LIGHT-ACTIVATED FLASHER



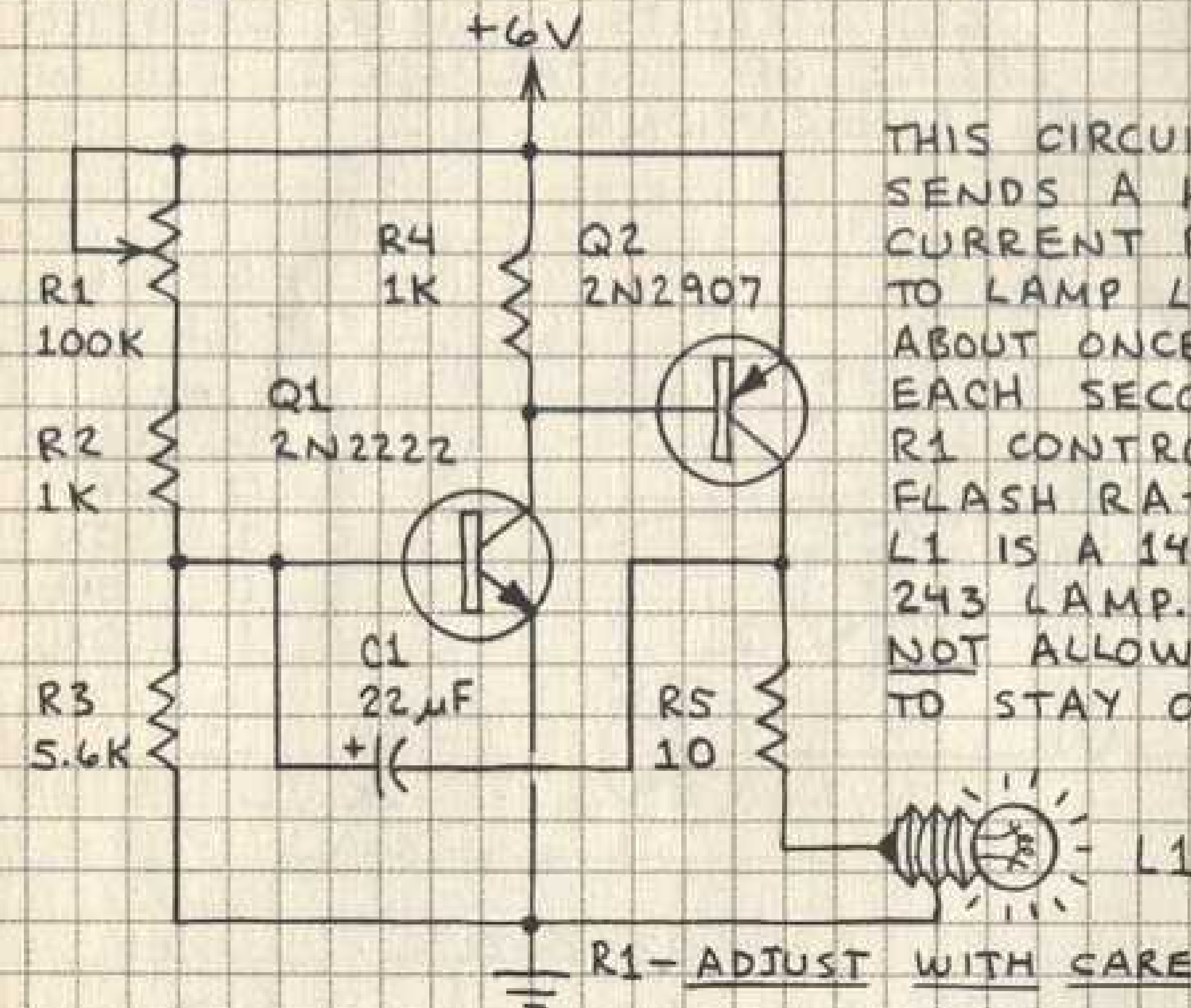
THE LED FLASHES WHEN Q1 IS ILLUMINATED BY SUNLIGHT OR ARTIFICIAL LIGHT. WHEN Q1 IS DARK, THE FLASHER IS DISABLED. C1 CONTROLS THE FLASH RATE.

DARK-ACTIVATED FLASHER



THIS CIRCUIT CAN BE USED AS A WARNING FLASHER THAT TURNS ON AT NIGHT. C1 CONTROLS FLASH RATE.

HIGH-BRIGHTNESS FLASHER

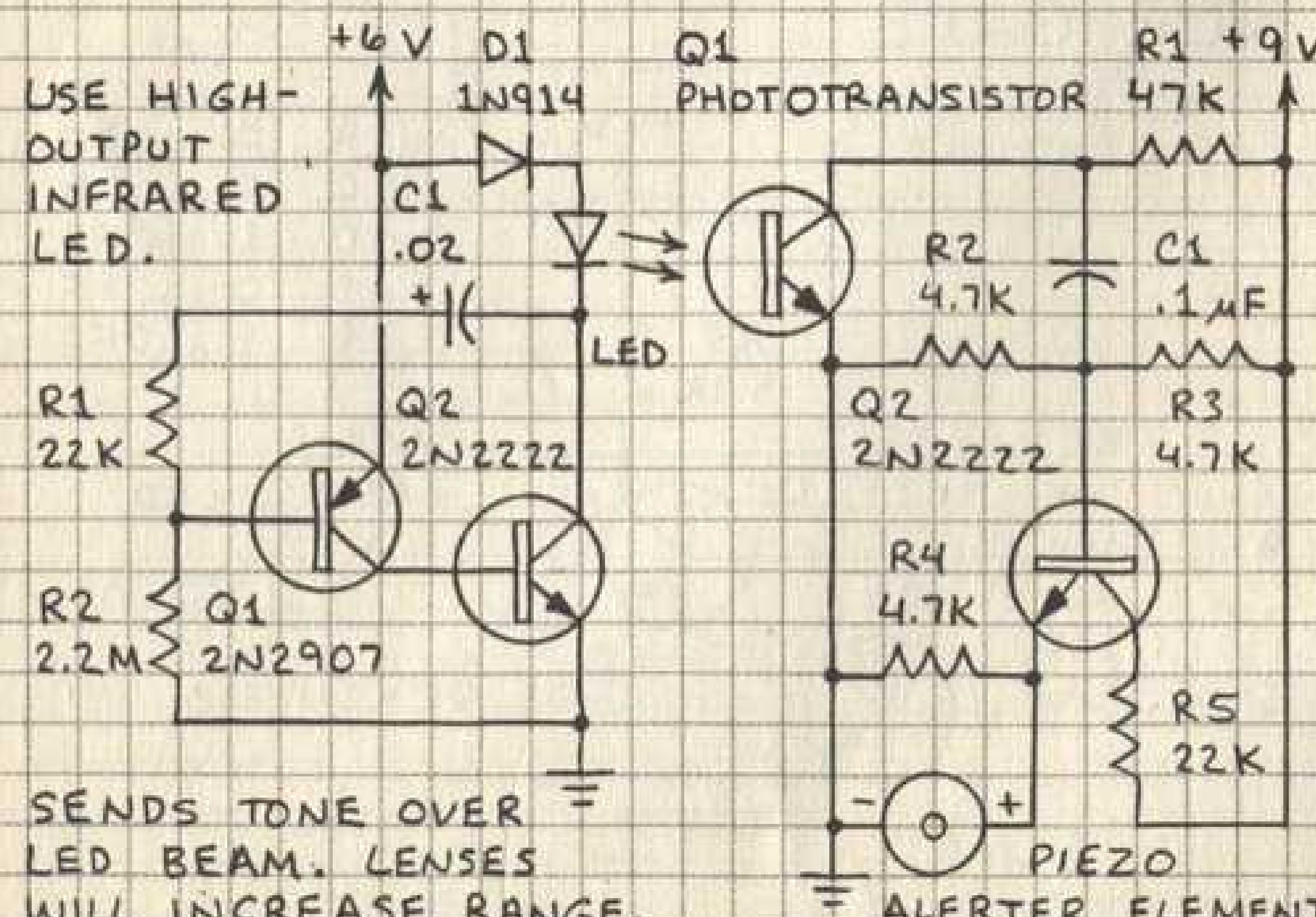


THIS CIRCUIT SENDS A HIGH-CURRENT PULSE TO LAMP L1 ABOUT ONCE EACH SECOND. R1 CONTROLS FLASH RATE. L1 IS A 14 OR 243 LAMP. DO <u>NOT</u> ALLOW L1 TO STAY ON.

R1- <u>ADJUST</u> <u>WITH</u> <u>CARE</u>.

LED TRANSMITTER/RECEIVER

USE HIGH-OUTPUT INFRARED LED.



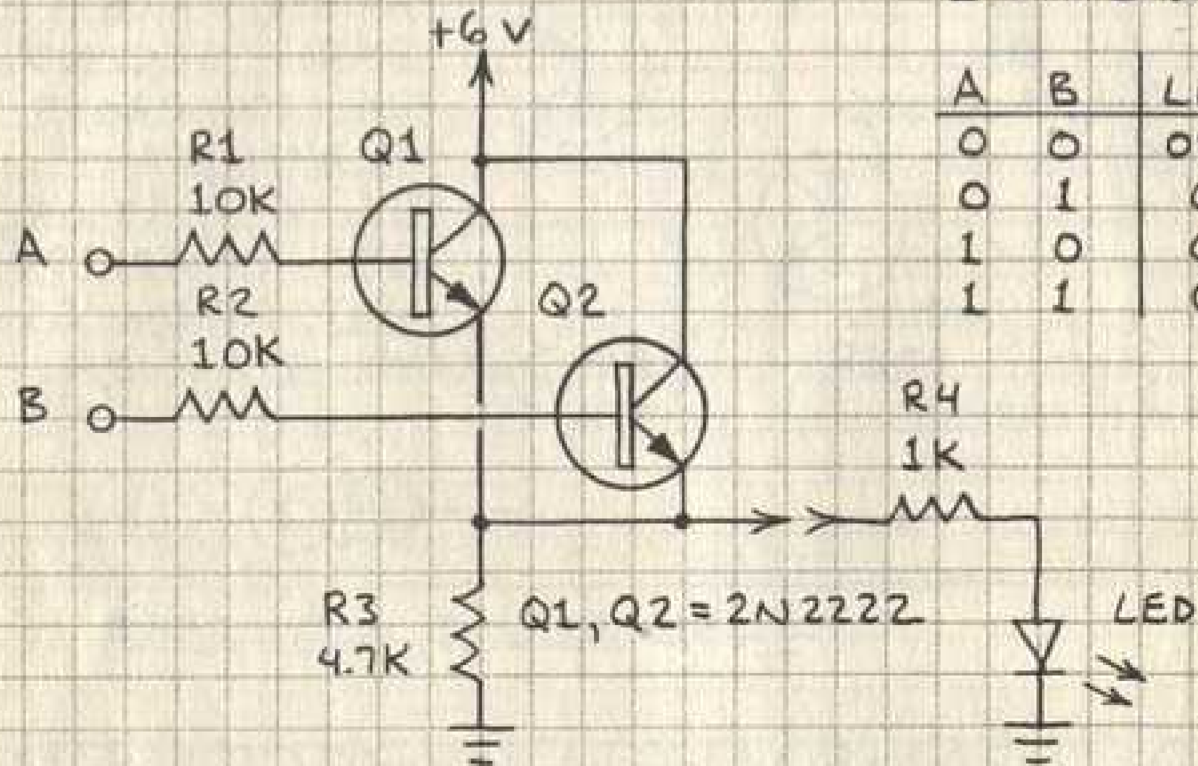
SENDS TONE OVER LED BEAM. LENSES WILL INCREASE RANGE.

RESISTOR-TRANSISTOR LOGIC

THESE LOGIC CIRCUITS CAN BE USED TO TEACH BASICS OF DIGITAL LOGIC AND IN PRACTICAL APPLICATIONS.

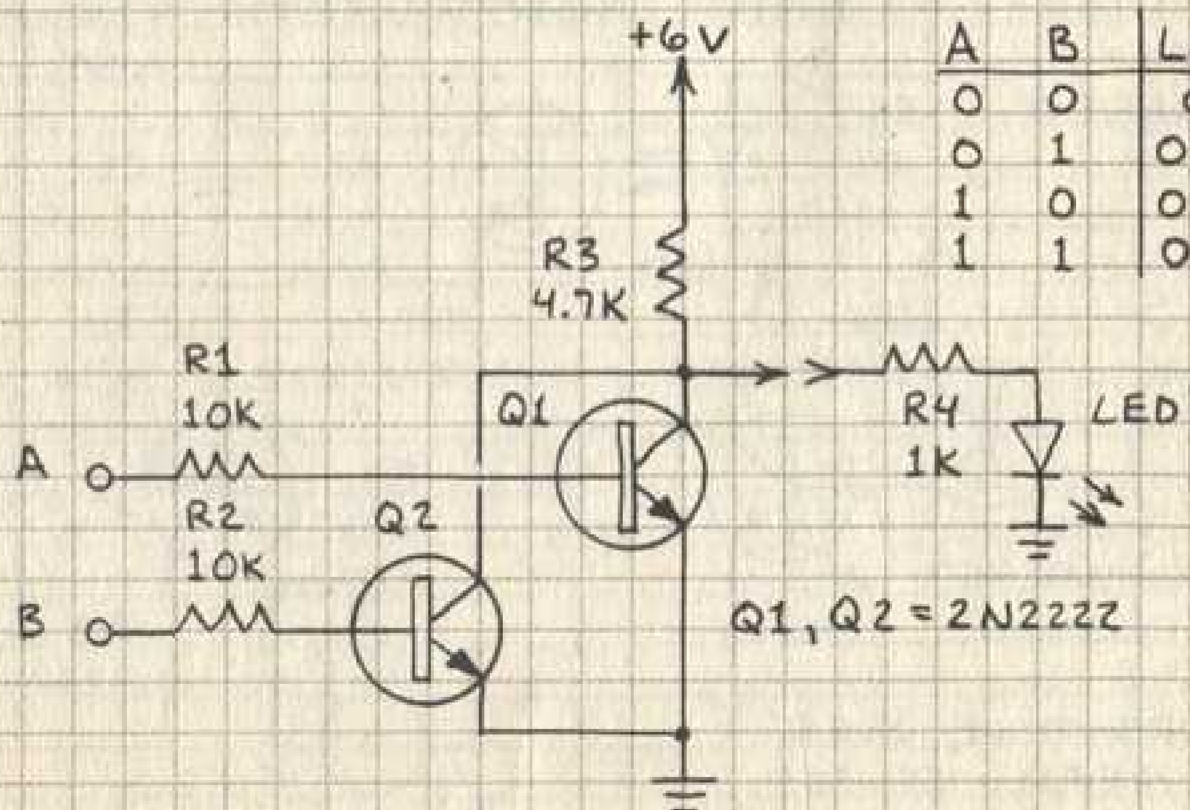
OR GATE

0 = GROUND
1 = +6 V



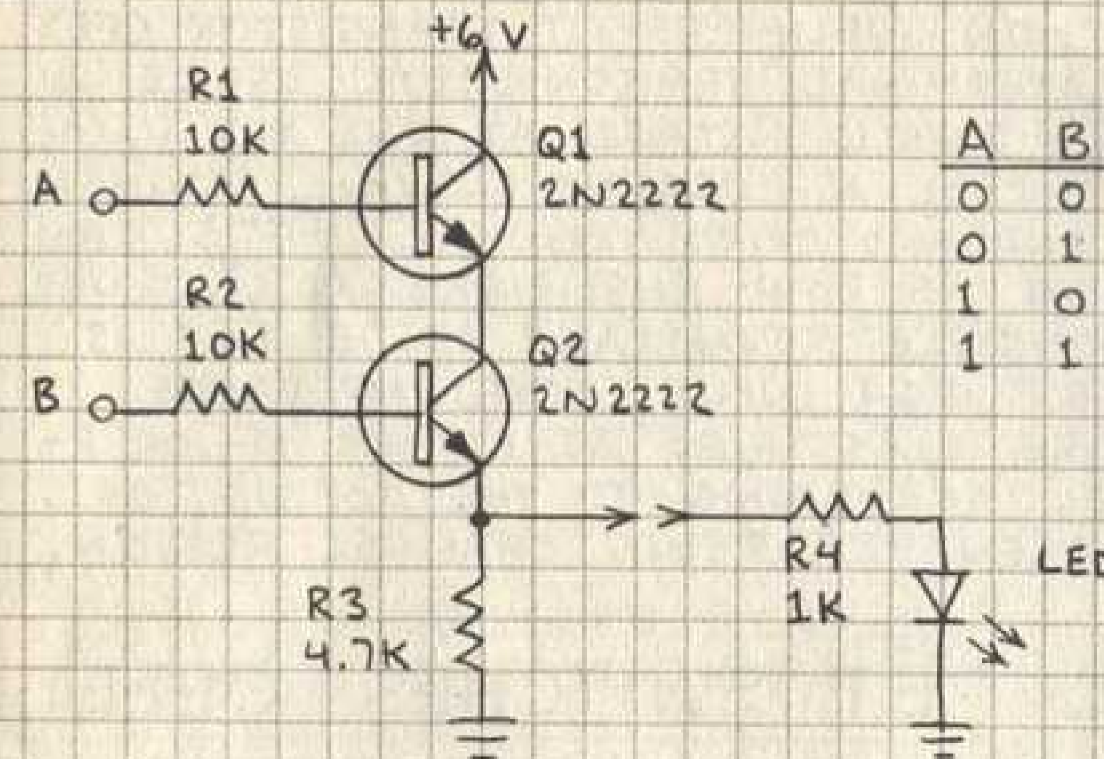
A	B	LED
0	0	OFF
0	1	ON
1	0	ON
1	1	ON

NOR GATE



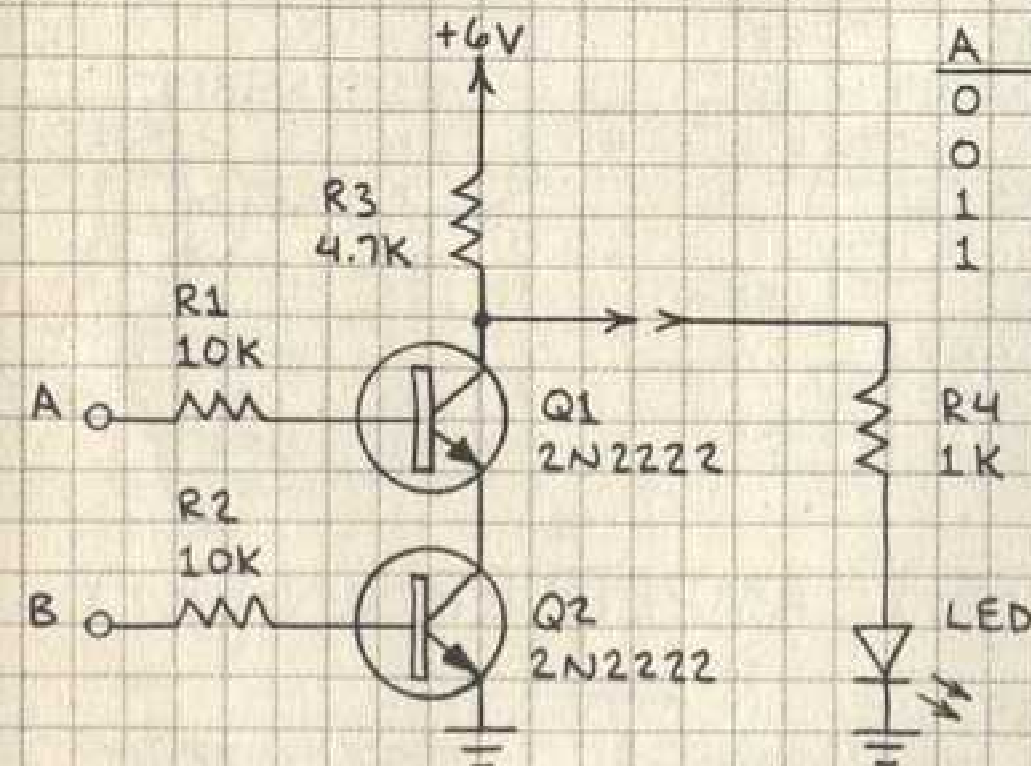
A	B	LED
0	0	ON
0	1	OFF
1	0	OFF
1	1	OFF

AND GATE



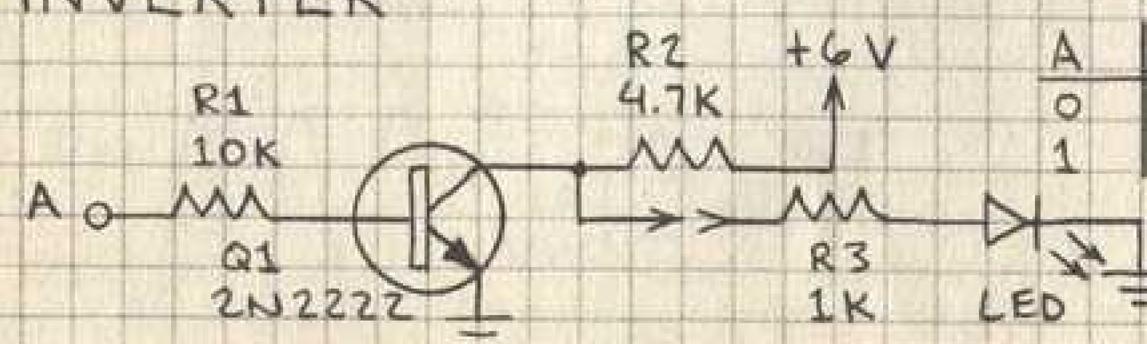
A	B	LED
0	0	OFF
0	1	OFF
1	0	OFF
1	1	ON

NAND GATE



A	B	LED
0	0	ON
0	1	ON
1	0	ON
1	1	OFF

INVERTER

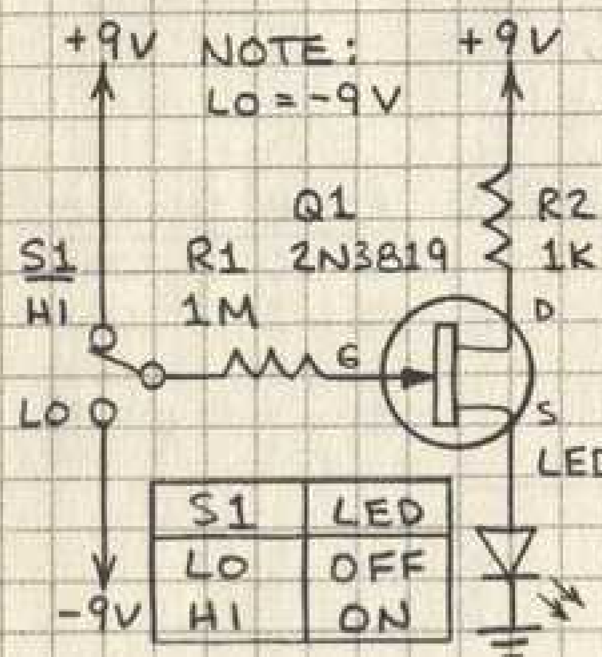


A	LED
0	ON
1	OFF

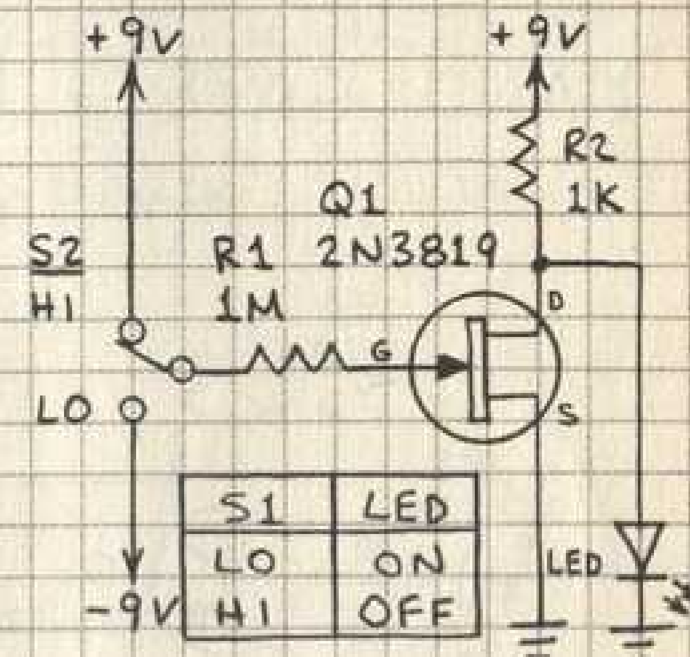
JUNCTION FETS

A JUNCTION FIELD-EFFECT TRANSISTOR (FET) IS A 3-TERMINAL SEMICONDUCTOR DEVICE IN WHICH A SMALL VOLTAGE AT ONE TERMINAL CAN CONTROL A CURRENT FLOWING BETWEEN THE SECOND AND THIRD TERMINAL. FETS CAN FUNCTION AS BOTH AMPLIFIERS AND SWITCHES. THE PRINCIPLE ADVANTAGE OF THE FET IS ITS VERY HIGH INPUT (GATE) IMPEDANCE. FETS ARE CLASSIFIED AS EITHER N- OR P-CHANNEL ACCORDING TO THE DOPING OF THE CURRENT-CARRYING CHANNEL REGION.

BASIC FET SWITCHES (N-FET)

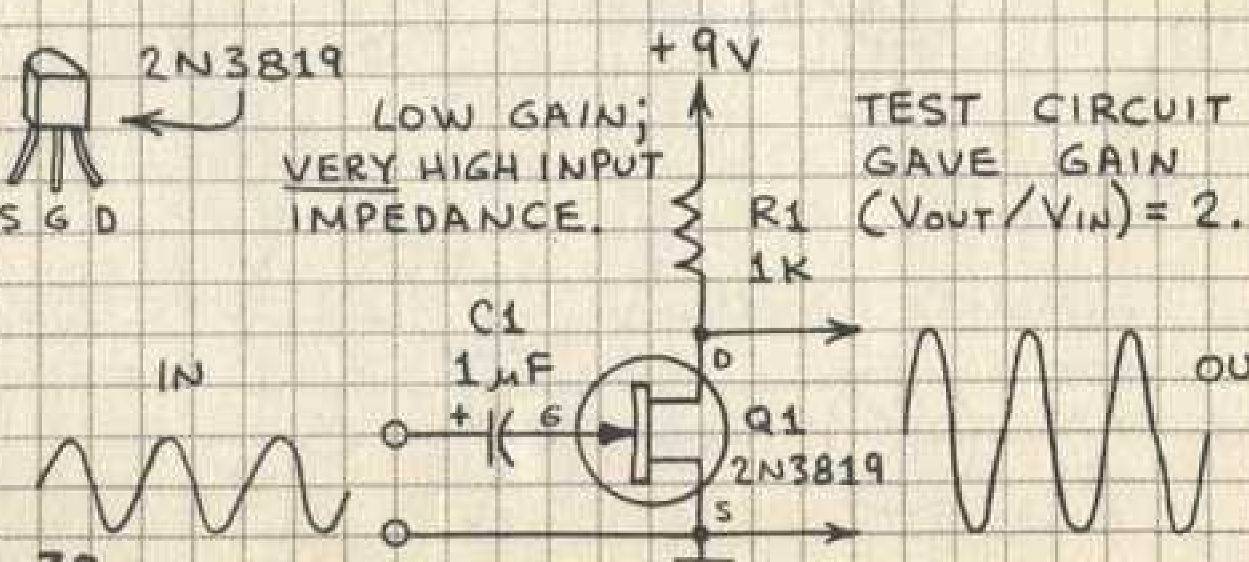


S1	LED
LO	OFF
HI	ON



S1	LED
LO	ON
HI	OFF

BASIC FET AMPLIFIER (N-FET)



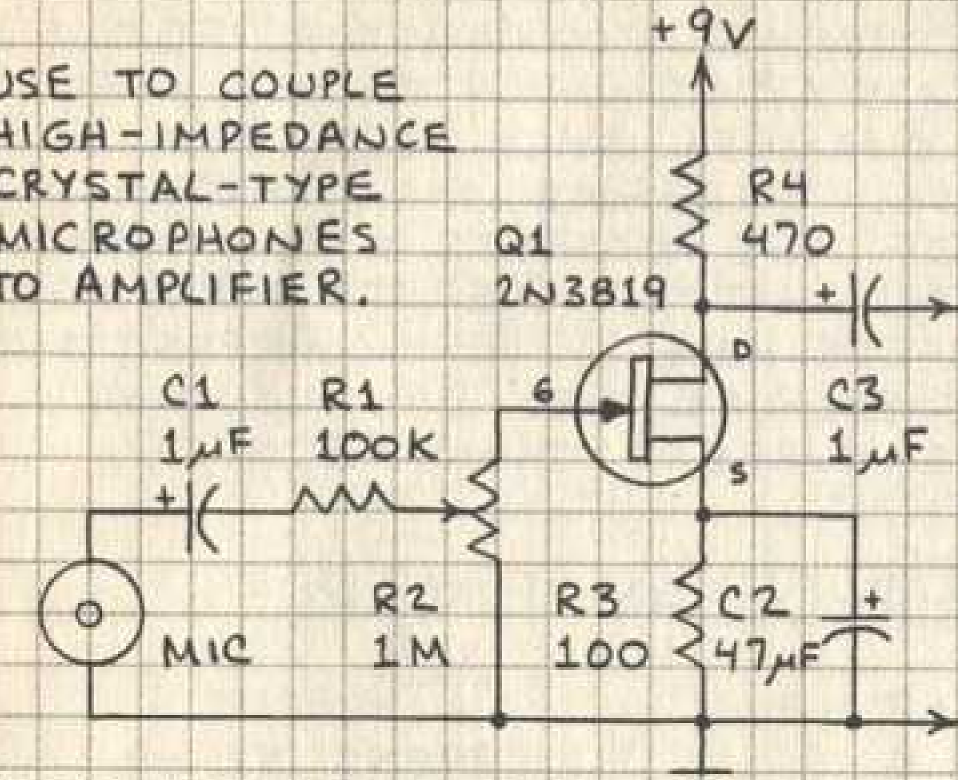
LOW GAIN; VERY HIGH INPUT IMPEDANCE.

TEST CIRCUIT GAVE GAIN $(V_{OUT}/V_{IN}) = 2$.

HI-Z MICROPHONE PREAMPLIFIER

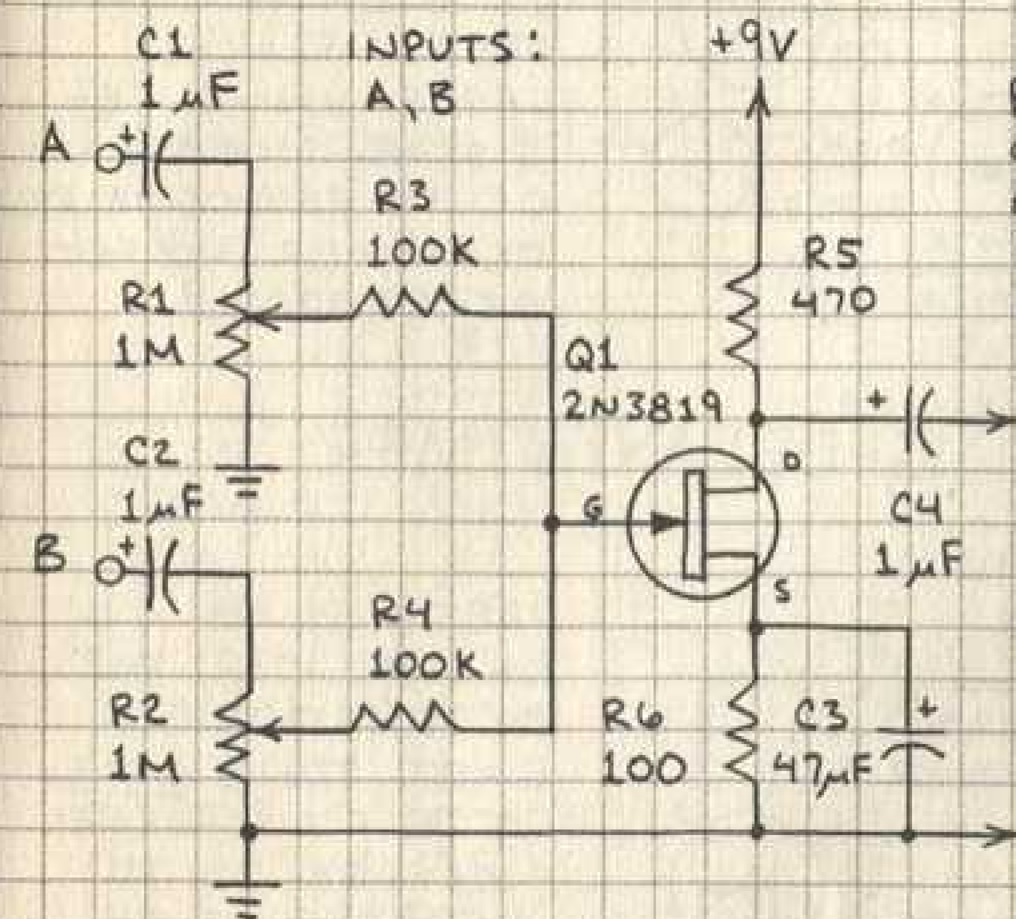
USE TO COUPLE HIGH-IMPEDANCE CRYSTAL-TYPE MICROPHONES TO AMPLIFIER.

R2 IS GAIN CONTROL.



KEEP LEADS TO MICROPHONE SHORT OR USE SHIELDED CABLE.

HI-Z AUDIO MIXER



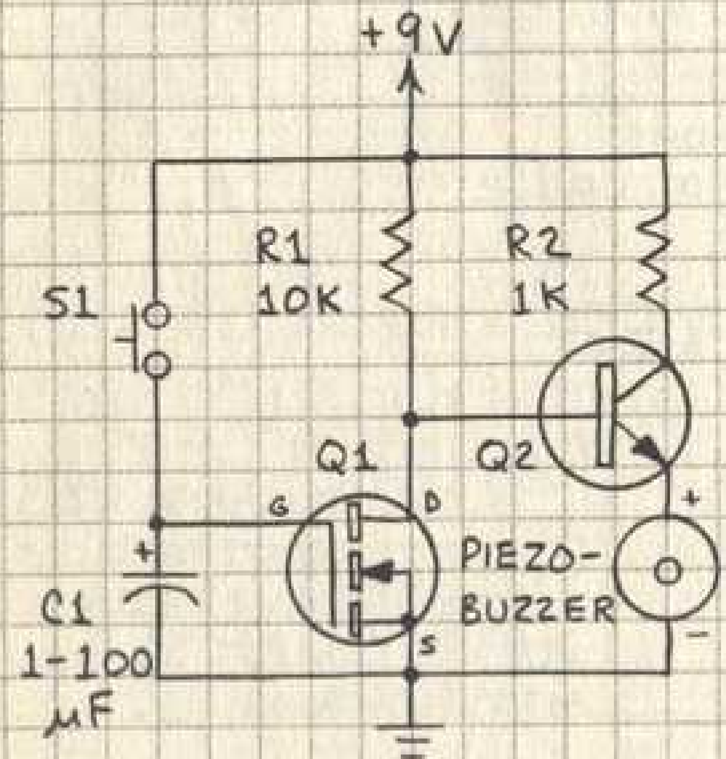
R1 AND R2 CONTROL GAIN FOR INPUTS A AND B.

USE TO COMBINE SIGNALS FROM TWO OR MORE MICROPHONES, PREAMPLIFIERS, ETC.

POWER MOSFETS

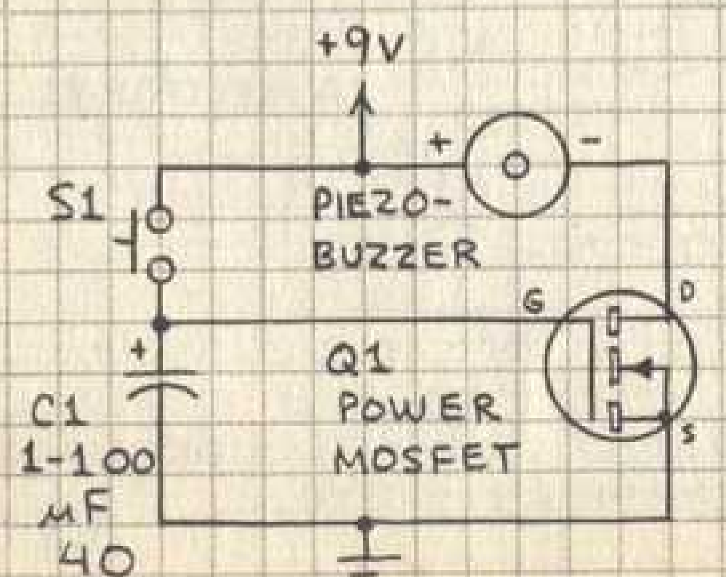
A METAL-OXIDE-SEMICONDUCTOR FET (MOSFET) HAS A GATE WHICH IS INSULATED FROM THE CHANNEL BY A VERY THIN GLASSY OXIDE. THEREFORE THE INPUT IMPEDANCE OF THE MOSFET IS CONSIDERABLY HIGHER THAN THAT OF THE STANDARD FET. POWER MOSFETS HAVE A VERY LOW RESISTANCE CHANNEL. THEREFORE THEY CAN CONTROL MUCH MORE CURRENT THAN FETS.

ON-AFTER-DELAY TIMER



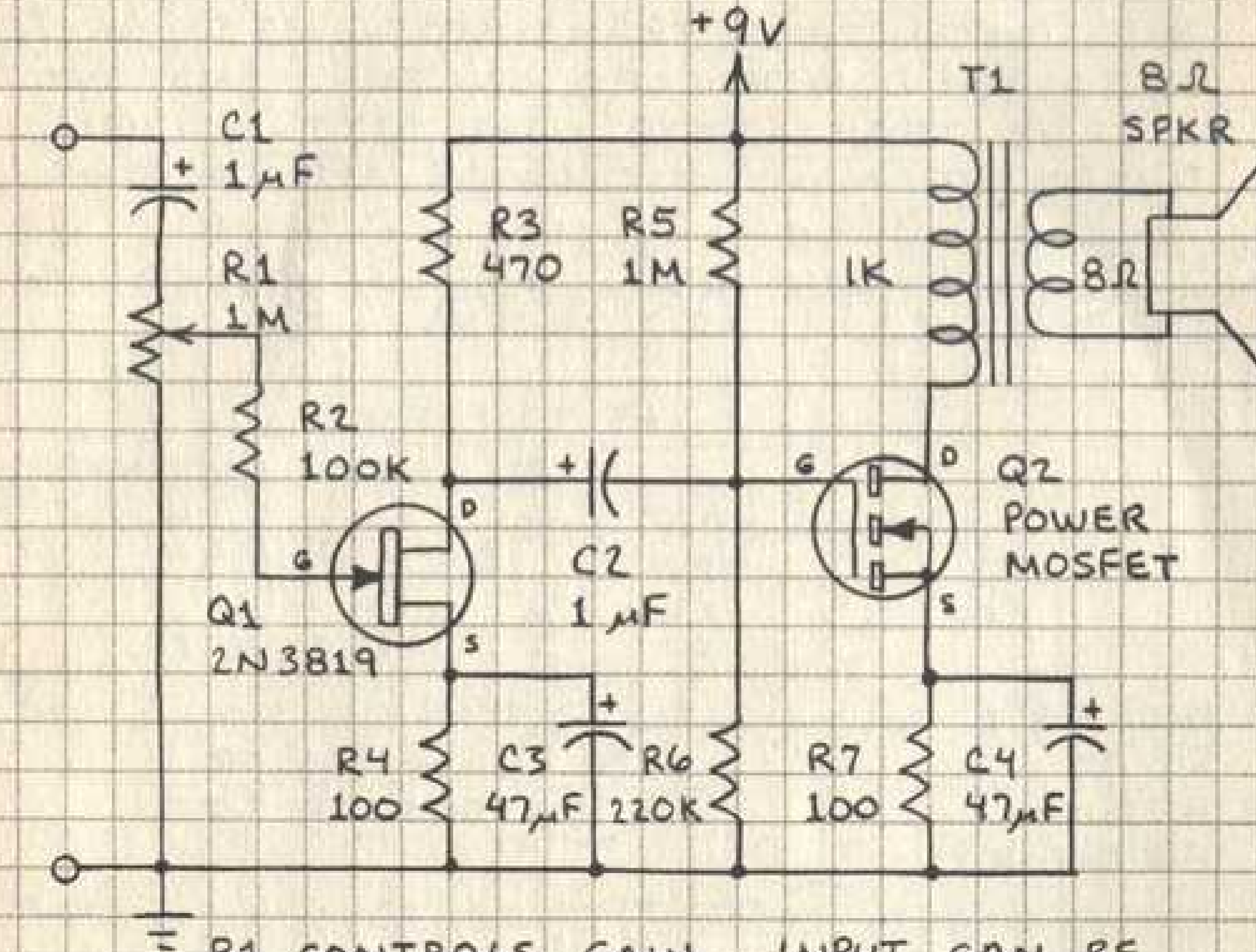
PRESS S1 TO CHARGE C1. THE PIEZO-BUZZER EMITS TONE AFTER C1 SELF DISCHARGES. LARGE VALUES FOR C1 INCREASE THE DELAY. PLACE LARGE VALUE RESISTOR ACROSS C1 TO REDUCE DELAY. Q1-POWER MOSFET. Q2-2N2222.

ON-DURING-DELAY TIMER



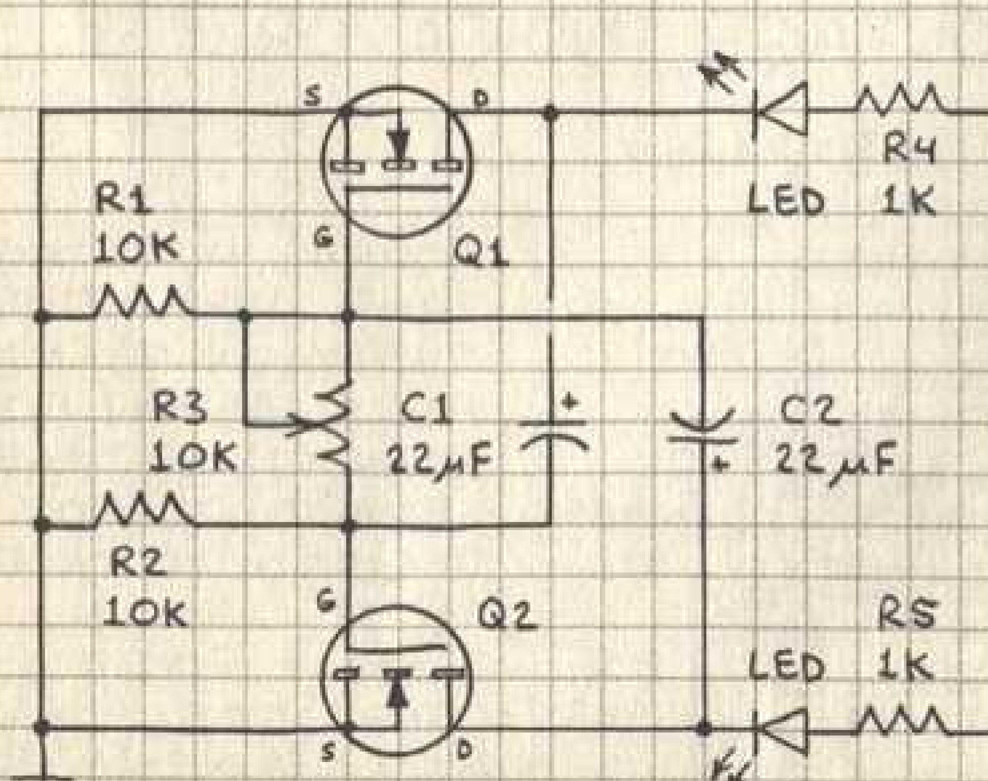
PRESS S1 TO CHARGE C1. THE PIEZO-BUZZER EMITS TONE UNTIL C1 SELF DISCHARGES. INCREASE C1 TO INCREASE DELAY. RESISTOR ACROSS C1 WILL REDUCE DELAY.

HI-Z SPEAKER AMPLIFIER



R1 CONTROLS GAIN. INPUT CAN BE HIGH-IMPEDANCE MICROPHONE, RADIO, ETC.

DUAL LED FLASHER



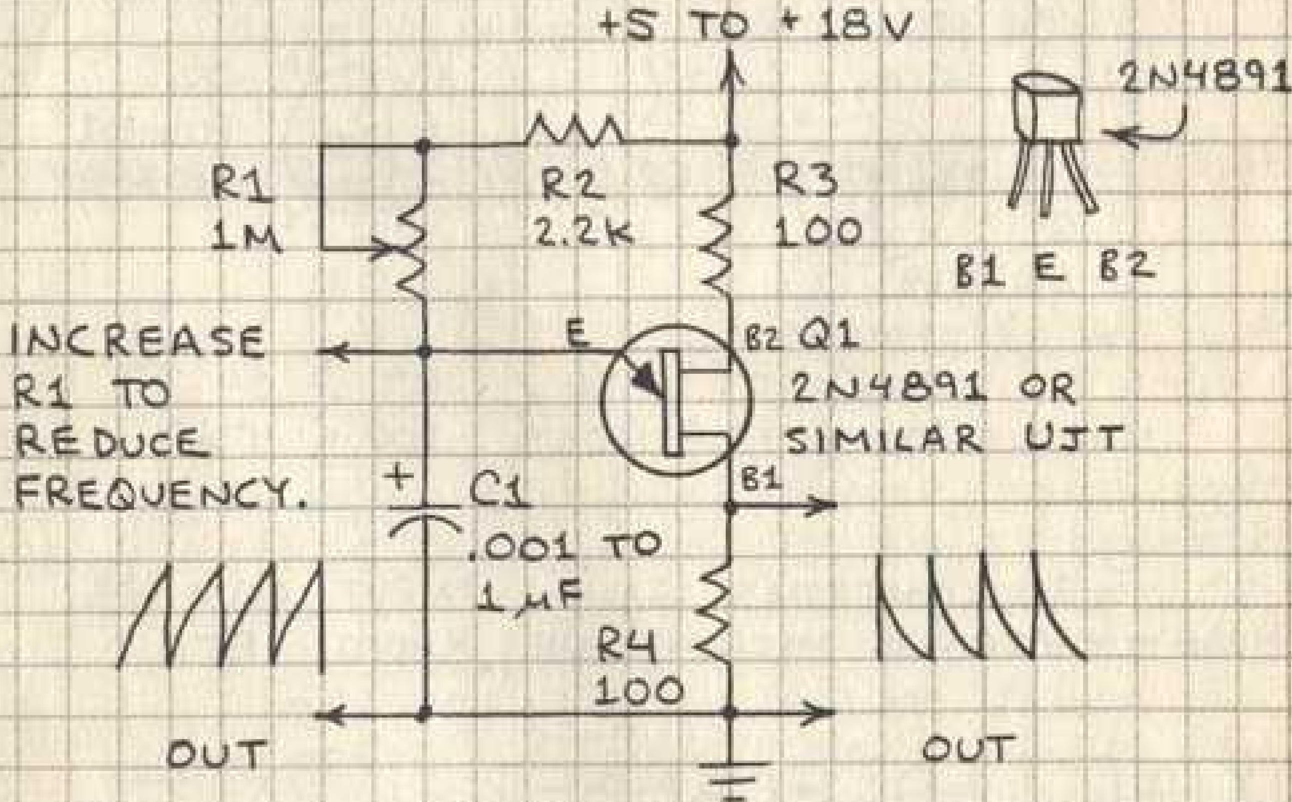
Q1, Q2-POWER MOSFETS

LEDS FLASH ALTERNATELY. R3 CONTROLS FLASH RATE. QUICKLY SHORT C1 OR C2 IF CIRCUIT FAILS TO FLASH.

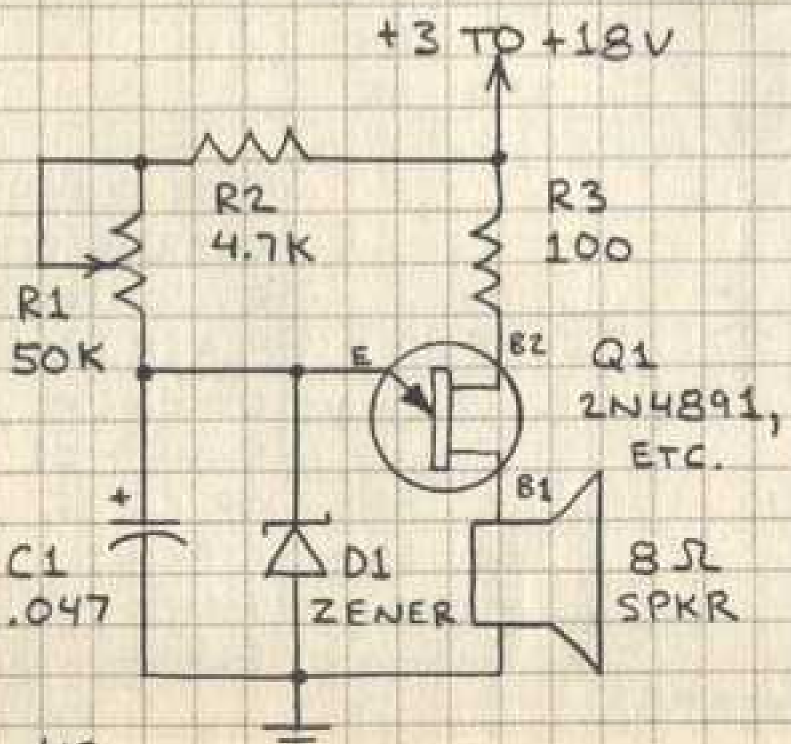
UNIJUNCTION TRANSISTORS

THE UNIJUNCTION TRANSISTOR (UJT) IS A VOLTAGE-CONTROLLED SWITCH AND NOT A TRUE TRANSISTOR. THE UJT IS WELL SUITED FOR MANY OSCILLATOR APPLICATIONS.

BASIC UJT OSCILLATOR

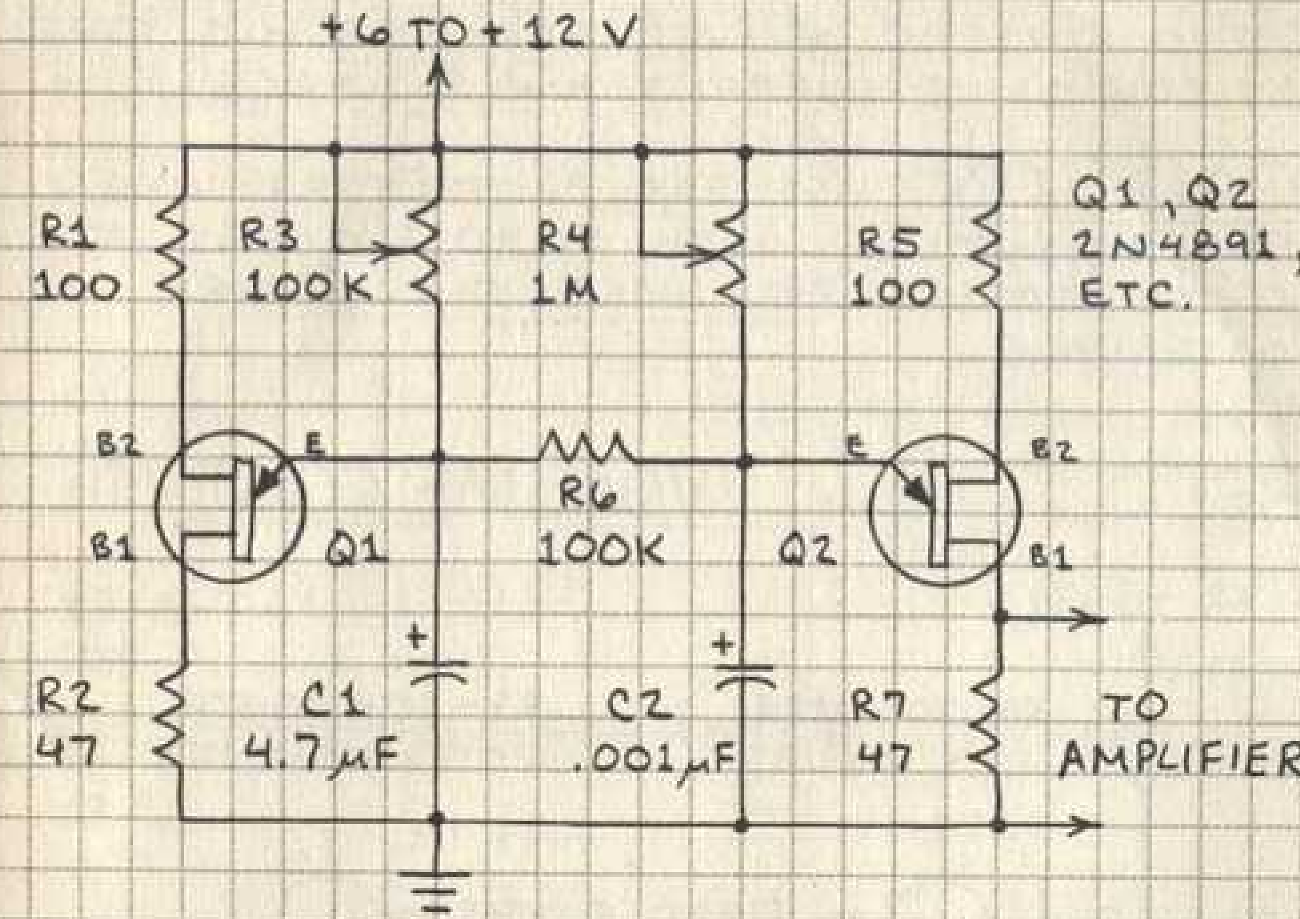


LOW-VOLTAGE INDICATOR



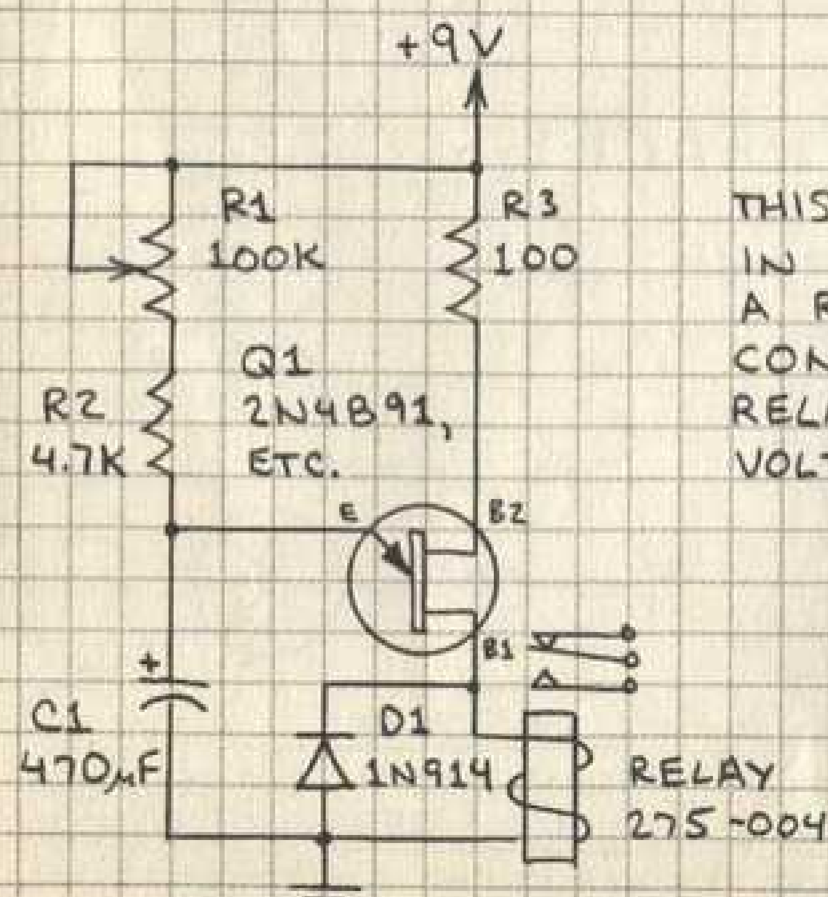
SOUNDS WARNING TONE WHEN THE SUPPLY VOLTAGE FALLS BELOW D1'S TURN-ON VOLTAGE. SELECT D1 FOR DESIRED VOLTAGE. OK TO USE A SINGLE FIXED CAPACITOR FOR R1 AND R2 (4.7K GIVES 2.8 KHz).

SOUND-EFFECTS GENERATOR



THIS CIRCUIT GENERATES CHIRPS HAVING A FREQUENCY CONTROLLED BY R4. R3 CONTROLS RATE.

1-MINUTE TIMER



THIS CIRCUIT PULLS IN THE RELAY AT A REPETITIVE CYCLE CONTROLLED BY R1. RELAY <u>MUST</u> BE LOW-VOLTAGE TYPE.

R1 + R2 (OHMS)	DELAY (SEC.)
10K	7
15K	10
22K	12
47K	27
100K	68

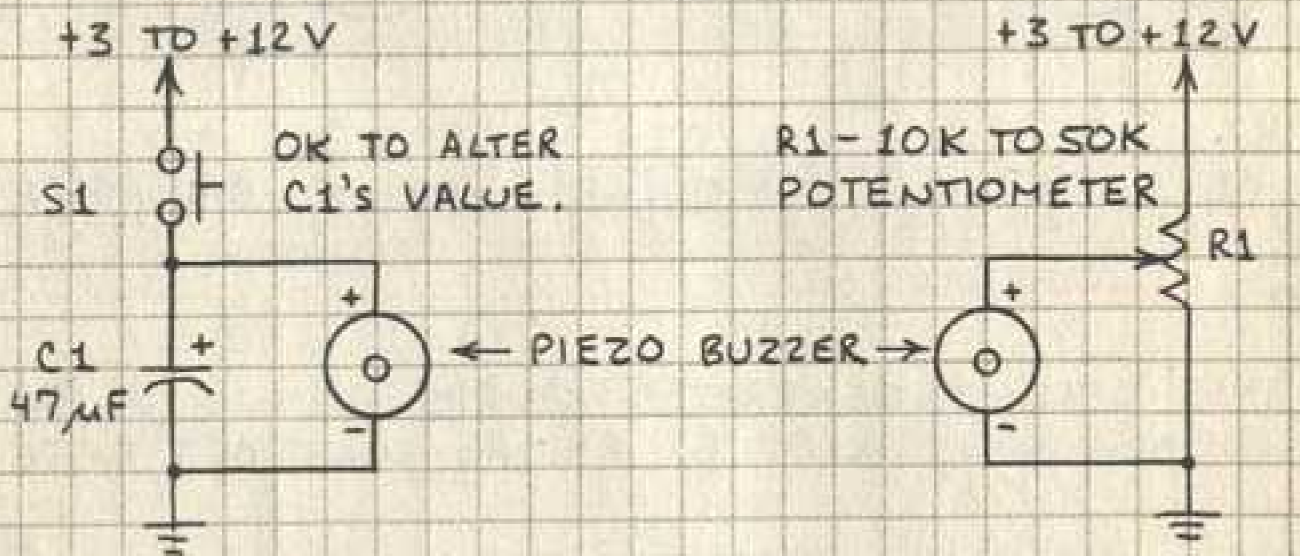
PIEZOELECTRIC BUZZERS

PIEZO BUZZERS DELIVER EAR-PIERCING TONE AT LOW DRIVE CURRENT AND VOLTAGE.

CAUTION: USE EAR PROTECTORS WHEN EXPERIMENTING WITH PIEZO BUZZERS AT CLOSE RANGE FOR MORE THAN BRIEF INTERVALS.

BELL

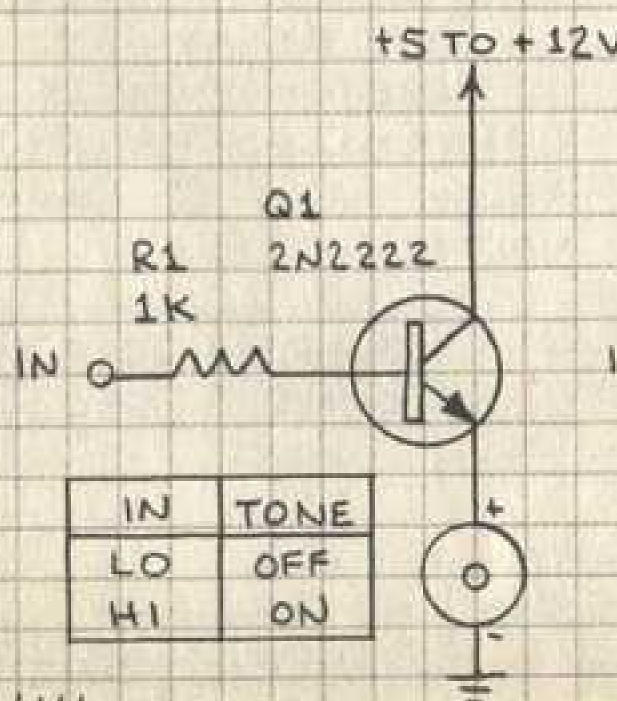
VOLUME CONTROL



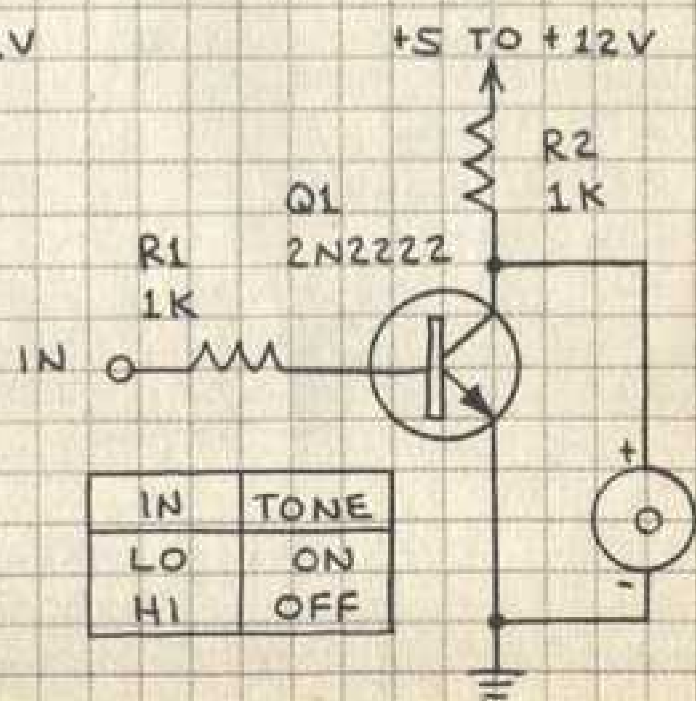
PRESS AND RELEASE S1 TO SIMULATE BELL.

R1 CONTROLS VOLUME.

LOGIC INTERFACES



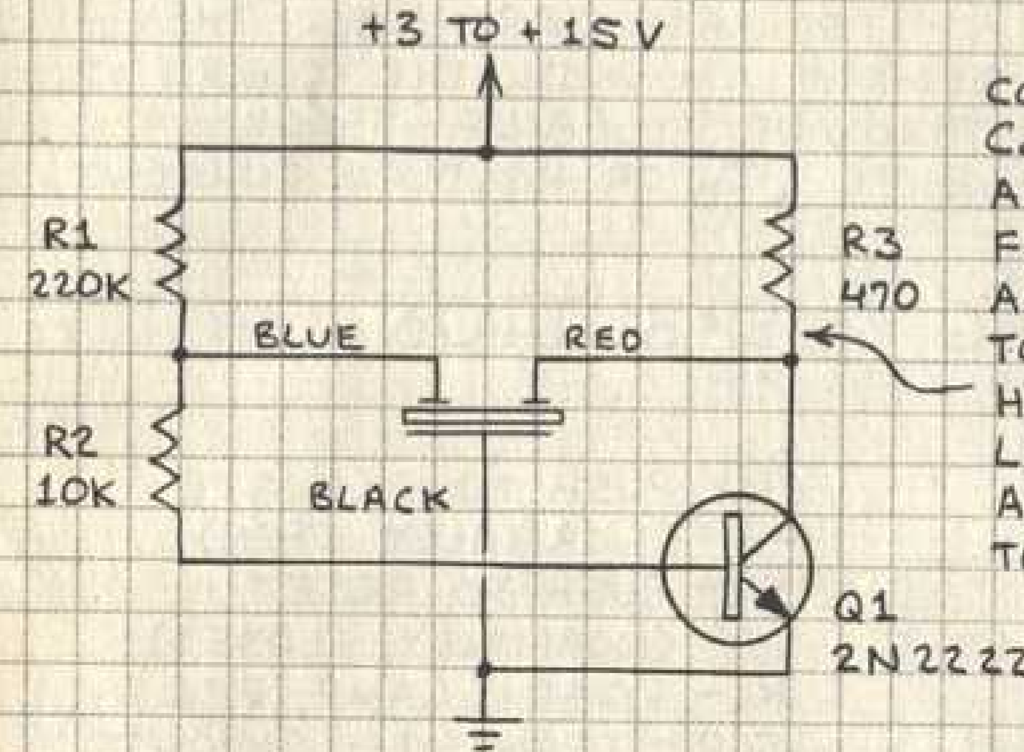
IN	TONE
LO	OFF
HI	ON



IN	TONE
LO	ON
HI	OFF

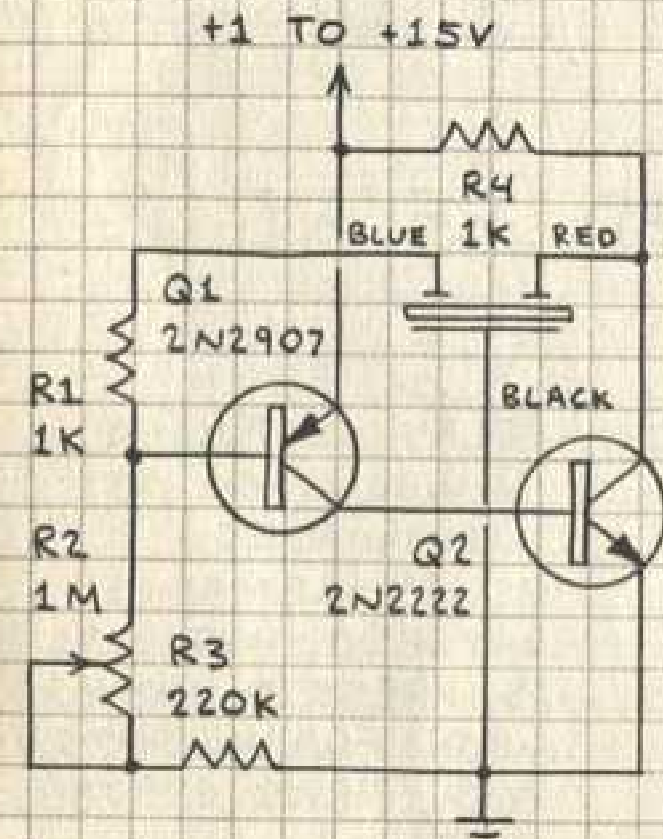
PIEZO-ELEMENT DRIVERS

FIXED TONE

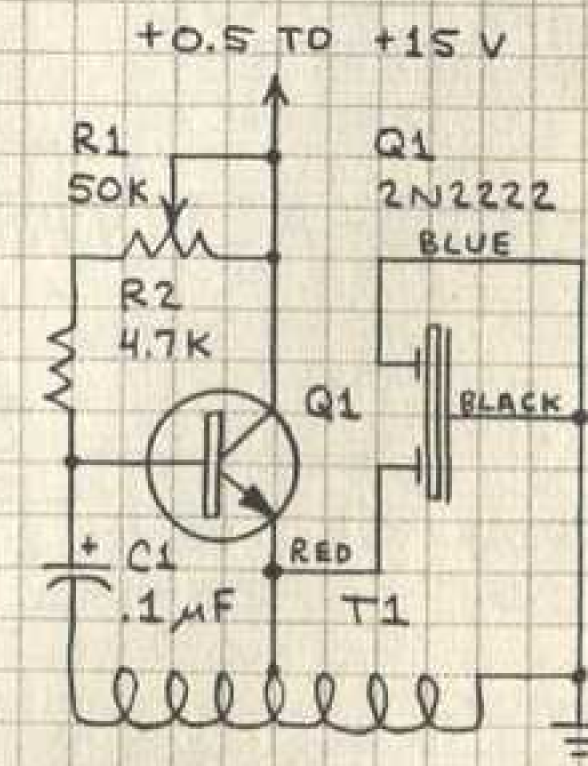


CONNECT CdS CELL ACROSS R1 FOR DARK-ACTIVATED TONE OR HERE FOR LIGHT-ACTIVATED TONE.

ADJUSTABLE FREQUENCY



THIS CIRCUIT CAN BE EASILY MINIATURIZED. R2 CONTROLS FREQUENCY.

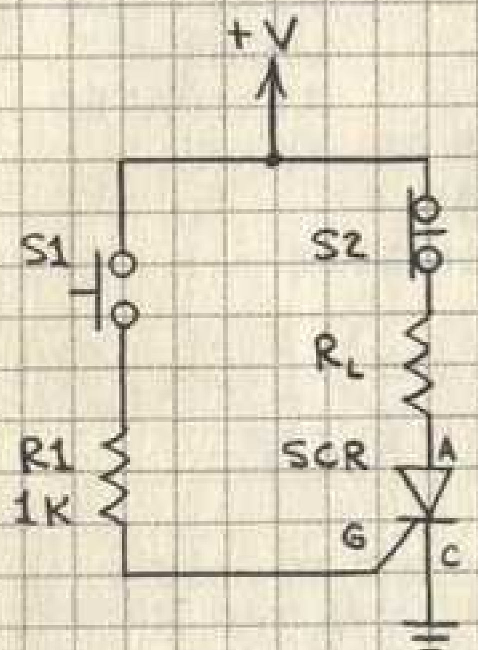


T1 IS PRIMARY OF CENTER-TAPPED AUDIO TRANSFORMER (RADIO SHACK 273-1380). R1 CONTROLS FREQUENCY.

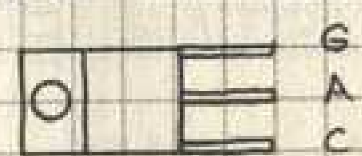
SILICON-CONTROLLED RECTIFIERS

THE SILICON-CONTROLLED RECTIFIER (SCR) IS A TRUE SOLID-STATE ON-OFF SWITCH. THE SCR IS SWITCHED ON BY A SMALL CURRENT AT ITS GATE TERMINAL. THE SCR WILL REMAIN ON UNTIL THE CURRENT FLOWING THROUGH IT FALLS BELOW A MINIMUM LEVEL (I_H OR HOLDING CURRENT).

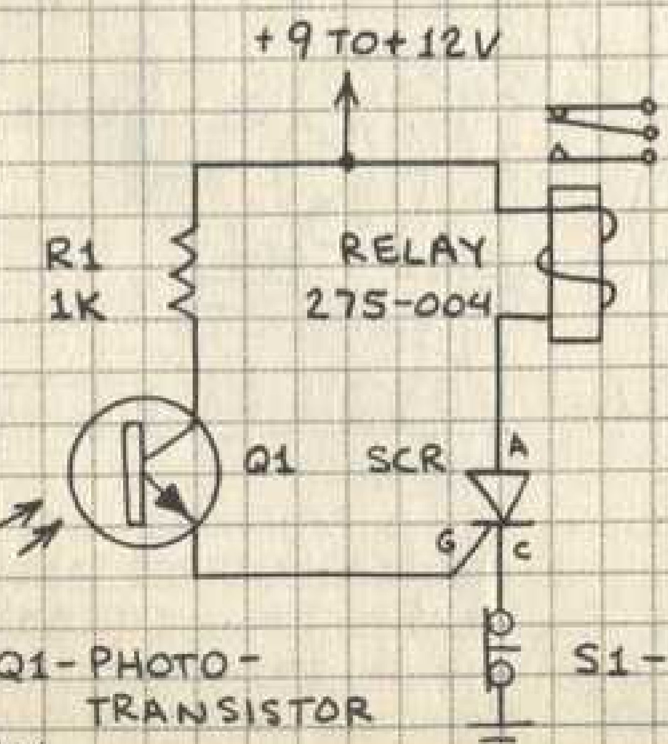
LATCHING PUSHBUTTON SWITCH



S1- PUSH TO ACTUATE (NORMALLY OPEN)
S2- PUSH TO RESET (NORMALLY CLOSED)
R_L- LOAD (LAMP, ETC.)
SCR - TERMINAL PINOUTS VARY. TYPICAL:



LIGHT-ACTIVATED RELAY

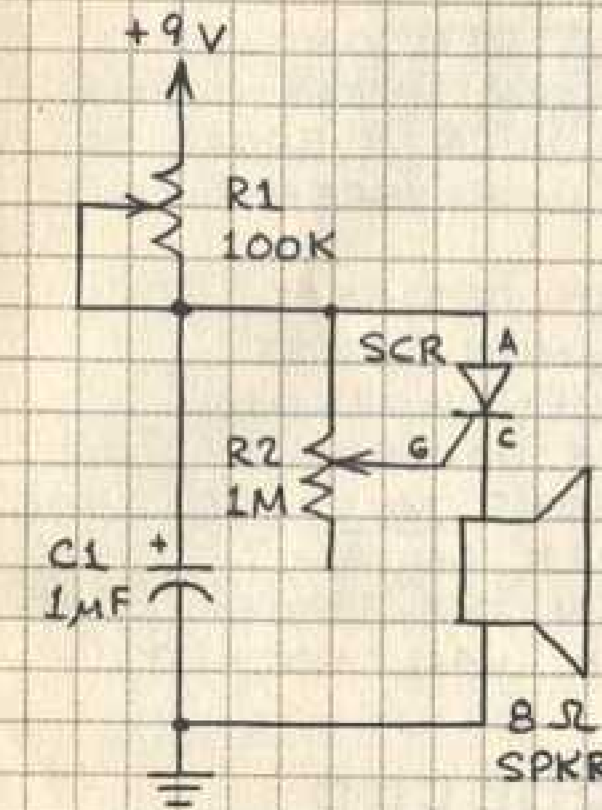


RELAY IS PULLED IN WHEN Q1 IS ILLUMINATED. RELAY REMAINS LATCHED UNTIL S1 IS PRESSED. WORKS WITH FLASHLIGHTS AND PHOTO STROBE UNITS.

Q1- PHOTO-TRANSISTOR

S1- PUSH TO RESET (NORMALLY CLOSED)

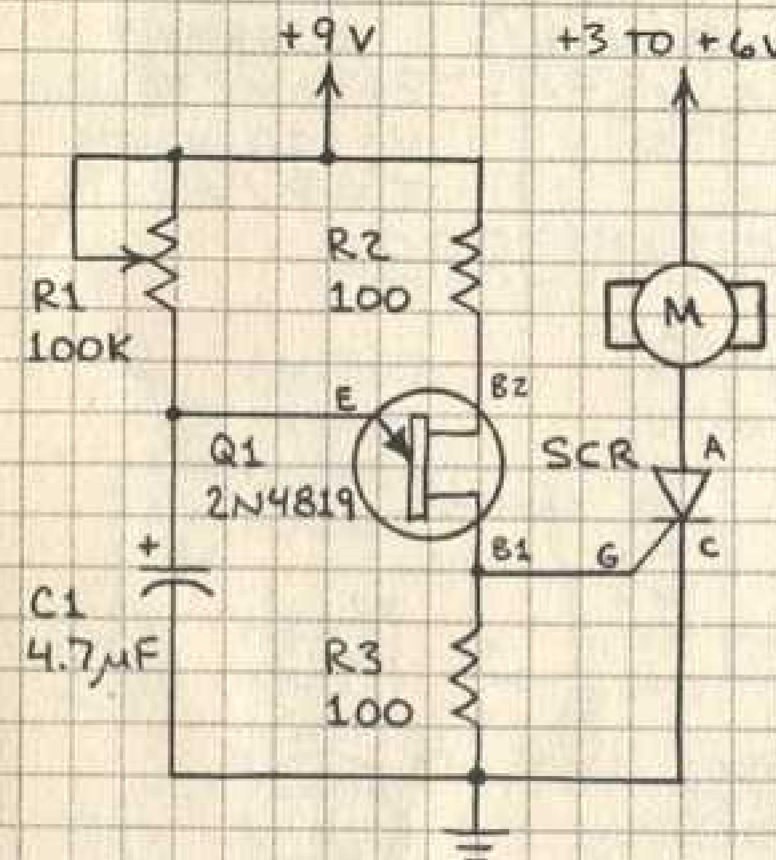
RELAXATION OSCILLATOR



C1 IS CHARGED THROUGH R1 UNTIL ITS CHARGE IS HIGH ENOUGH TO SWITCH ON THE SCR THROUGH R2. C1 THEN DISCHARGES THROUGH THE SCR AND THE SPEAKER. R1 CONTROLS THE REPETION RATE.

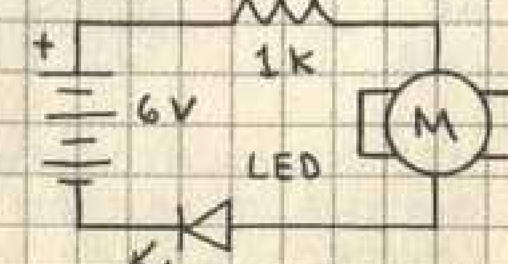
NOTE: SOME SCRs REQUIRE CAREFUL ADJUSTMENT OF R2.

DC MOTOR SPEED CONTROLLER



THIS CIRCUIT WILL VARY THE SPEED OF SELECTED* DC MOTORS. R4 CONTROLS THE SPEED. AT SLOW PULSE RATES FROM THE UJT OSCILLATOR, THE MOTOR WILL ROTATE IN BURSTS. FOR BEST RESULTS, USE A SEPARATE POWER SUPPLY FOR THE MOTOR.

*CHECK MOTOR WITH THIS CIRCUIT. IF LED FLASHES ON AND OFF WHEN SHAFT OF MOTOR IS ROTATED, IT WILL PROBABLY WORK.

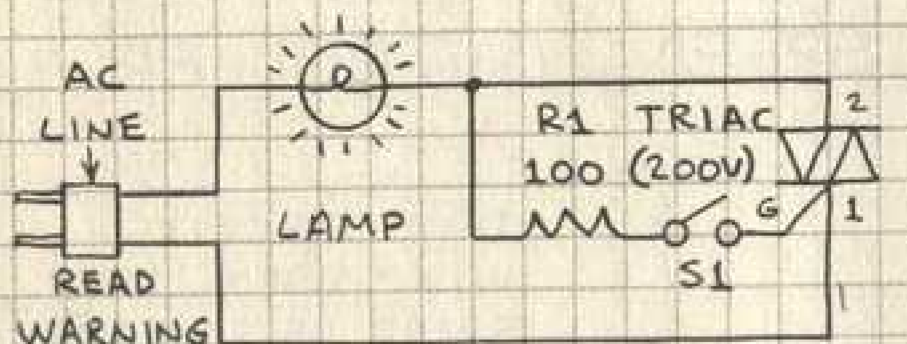


TRIACS

THE TRIAC IS A SOLID-STATE ON-OFF SWITCH THAT CAN CONTROL ALTERNATING CURRENT. IT IS ELECTRONICALLY EQUAL TO TWO SCRs CONNECTED IN REVERSE-PARALLEL.

<u>WARNING</u>: TRIACS ARE DESIGNED FOR AC OPERATION. USE COMMON SENSE SAFETY PRECAUTIONS WHEN WORKING WITH CIRCUITS THAT USE HOUSEHOLD LINE CURRENT. <u>ALL</u> CONNECTIONS <u>MUST</u> BE WELL INSULATED. <u>NEVER</u> WORK ON AN AC LINE POWERED CIRCUIT WHEN THE POWER CORD PLUG IS INSERTED IN A WALL SOCKET.

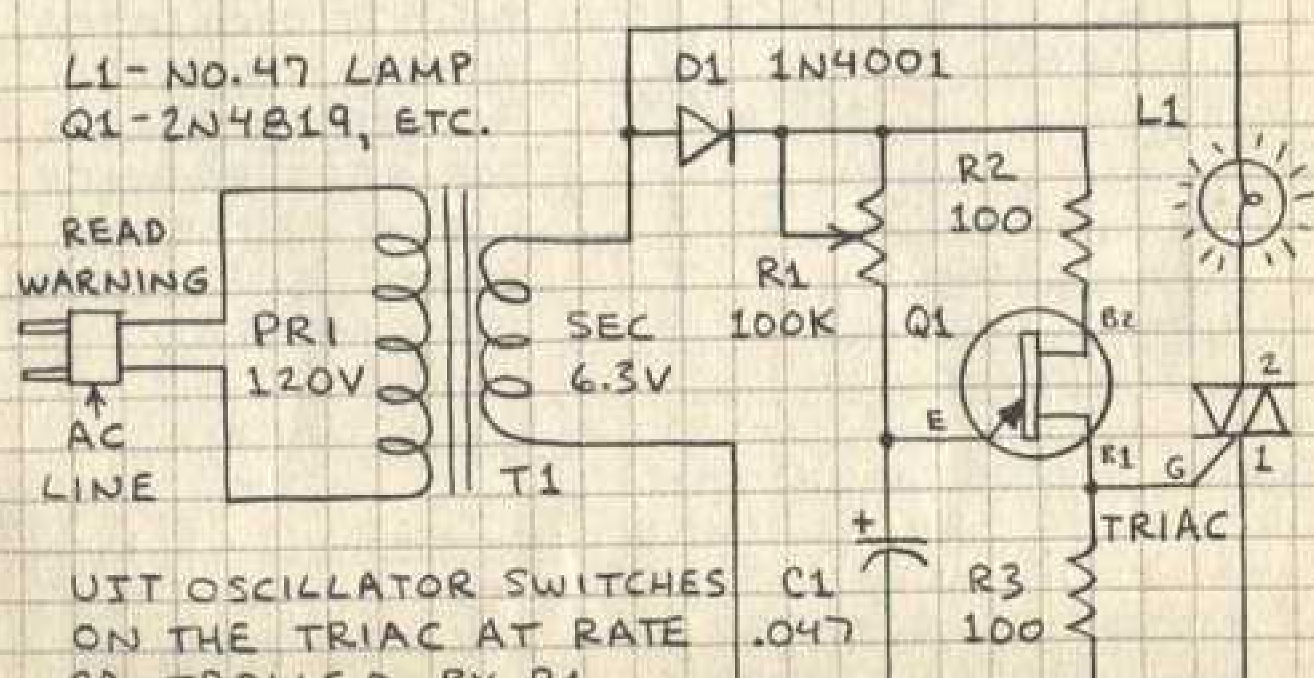
TRIAC SWITCH BUFFER



I = TRIAC CURRENT
P = LAMP POWER
V = 120 VOLTS
I = P/V

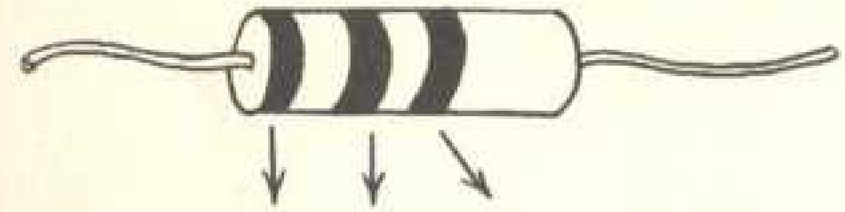
LAMP DIMMER

L1- NO. 47 LAMP
Q1-2N4819, ETC.



UJT OSCILLATOR SWITCHES ON THE TRIAC AT RATE CONTROLLED BY R1.

RESISTOR COLOR CODE



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	—

FOURTH BAND INDICATES TOLERANCE (ACCURACY):
GOLD = ±5%   SILVER = ±10%   NONE = ±20%

OHM'S LAW:

$V = IR$ $R = V/I$
$I = V/R$ $P = VI = I^2R$

ABBREVIATIONS

A = AMPERE	R = RESISTANCE
F = FARAD	V (OR E) = VOLT
I = CURRENT	W = WATT
P = POWER	Ω = OHM

M (MEG-)	= × 1,000,000
K (KILO-)	= × 1,000
m (MILLI-)	= .001
µ (MICRO-)	= .000 001
n (NANO-)	= .000 000 001
p (PICO-)	= .000 000 000 001