ENGINEER'S Mini Notebook

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- Tone burster
- Chirp generator
- Gated oscillator
- Pulse generator
- Frequency meter
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- Sound meter
- Bargraph
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- Photophone
- Light sensitive circuits
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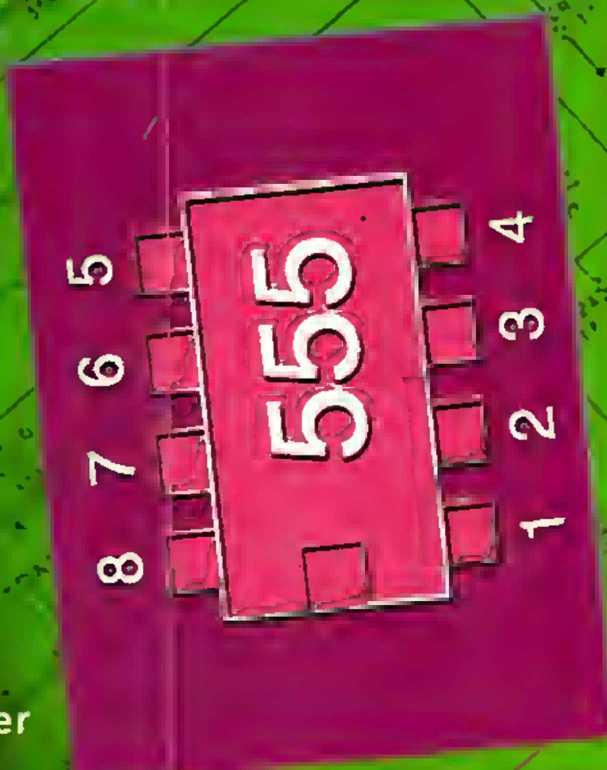
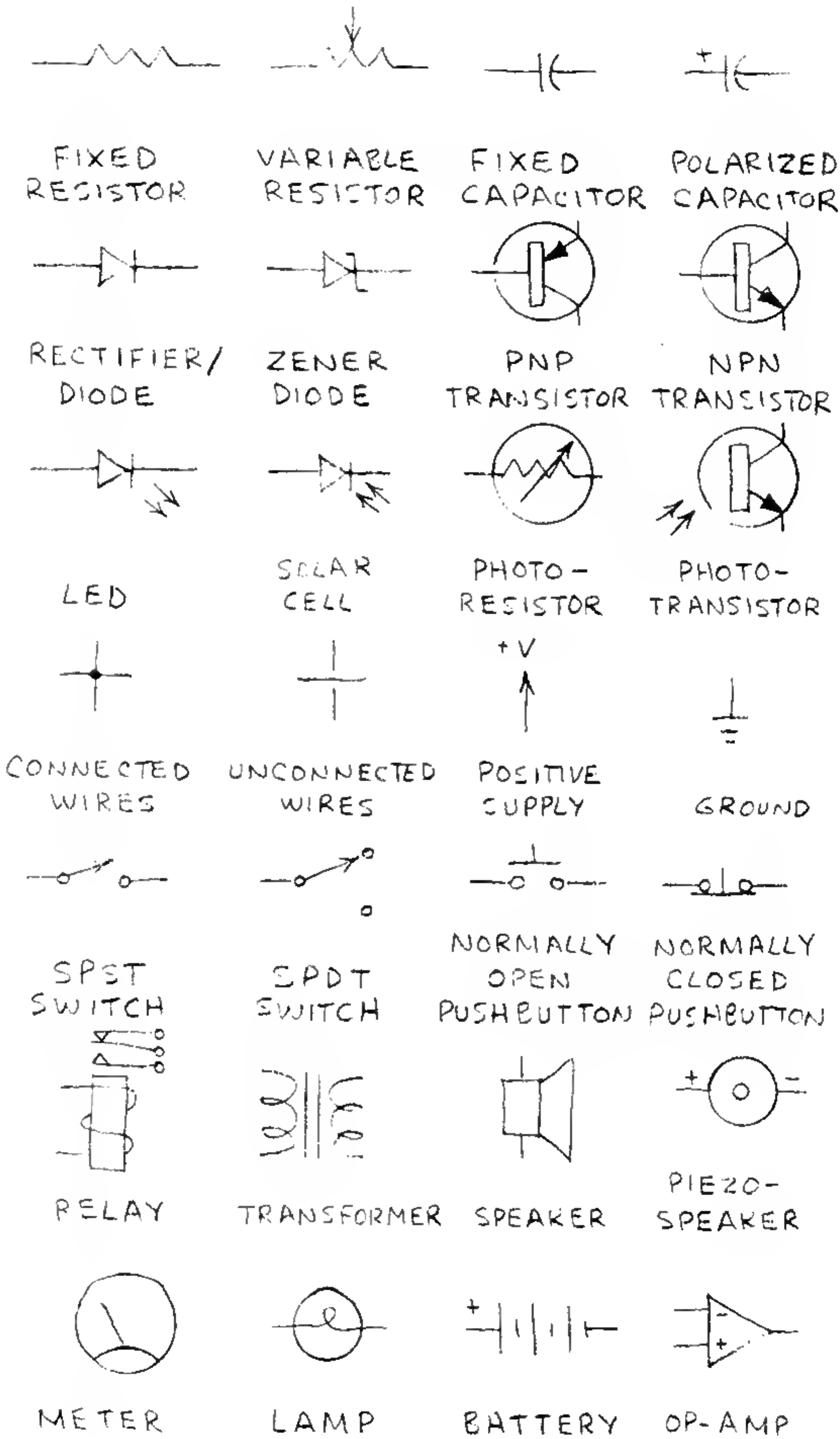


Forrest M. Mims III

CIRCUIT SYMBOLS



ENGINEER'S MINI-NOTEBOOK COLLECTION

TIMERS, OP AMPS AND OPTOELECTRONICS

BY

FORREST M. MIMS III

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ABOUT THE ENGINEER'S MINI-NOTEBOOK COLLECTION

EACH BOOK IN THIS COLLECTION INCLUDES THREE OR FOUR ENGINEER'S MINI-NOTEBOOKS. EACH BOOK INCLUDES BOTH STANDARD CIRCUITS AND CIRCUITS DESIGNED BY FORREST M. MIMS III. EACH CIRCUIT WAS BUILT AND TESTED AT LEAST TWICE. THE CIRCUITS WERE ALSO BUILT FROM THE FINAL BOOK TO FIND ERRORS.

VARIATIONS IN COMPONENTS AND CONSTRUCTION METHODS MAY CAUSE YOUR RESULTS TO DIFFER FROM THOSE DESCRIBED HERE. THEREFORE THE AUTHOR AND RADIOSHACK ARE NOT RESPONSIBLE FOR THE SUITABILITY OF THE CIRCUITS FOR ANY APPLICATION. FOR EXAMPLE, THE CIRCUITS IN THIS BOOK SHOULD NOT BE USED FOR MEDICAL APPLICATIONS, SAFETY DEVICES, TRAFFIC CONTROLLERS OR ANY OTHER USE THAT MIGHT SOMEHOW RESULT IN DAMAGE TO PROPERTY OR INJURY TO YOU OR OTHERS. IT IS YOUR RESPONSIBILITY TO DETERMINE IF COMMERCIAL USE, SALE OR MANUFACTURE OF ANY DEVICE BASED ON INFORMATION IN THIS BOOK INFRINGES ANY PATENT, COPYRIGHT OR OTHER RIGHT.

FOR MORE INFORMATION

DUE TO THE MANY INQUIRIES RECEIVED BY THE AUTHOR AND RADIOSHACK, IT IS NOT POSSIBLE TO PROVIDE CUSTOM CIRCUIT DESIGNS AND TECHNICAL ADVICE. YOU CAN LEARN MORE ABOUT ELECTRONICS FROM OTHER BOOKS AVAILABLE FROM RADIOSHACK AND FROM RADIOSHACK LAB KITS. ELECTRONICS MAGAZINES ARE ALSO A GOOD SOURCE OF INFORMATION. VARIOUS ELECTRONICS SITES ON THE INTERNET AND WORLD WIDE WEB ARE ALSO VERY HELPFUL.

I. 555 TIMER IC PROJECTS

II. OP AMP PROJECTS

CIRCUITS

HISTORICAL NOTE

THE OPERATIONAL AMPLIFIER WAS DEVELOPED FOR USE IN ANALOG COMPUTERS IN THE 1940S. EARLY OP-AMPS USED VACUUM TUBES AND WERE LARGE IN SIZE AND CONSUMED CONSIDERABLE POWER. IN 1967 FAIRCHILD SEMICONDUCTOR INTRODUCED THE FIRST INTEGRATED CIRCUIT OP-AMP. TODAY'S IC OP-AMPS ARE FAR SUPERIOR TO THEIR VACUUM TUBE PREDECESSORS. AND THEY ARE MUCH SMALLER AND CAN BE PURCHASED FOR AS LITTLE AS A DOLLAR OR TWO.

III. OPTOELECTRONICS

I. 555 TIMER IC CIRCUITS

OVERVIEW

THE 555 TIMER IS ONE OF THE MOST POPULAR AND VERSATILE INTEGRATED CIRCUITS. IT INCLUDES 23 TRANSISTORS, 2 DIODES AND 16 RESISTORS. THE 556 IS A DUAL VERSION OF THE 555. BOTH THE 555 AND 556 ARE AVAILABLE IN LOW-POWER VERSIONS. THE 555 HAS TWO PRINCIPLE OPERATING MODES:

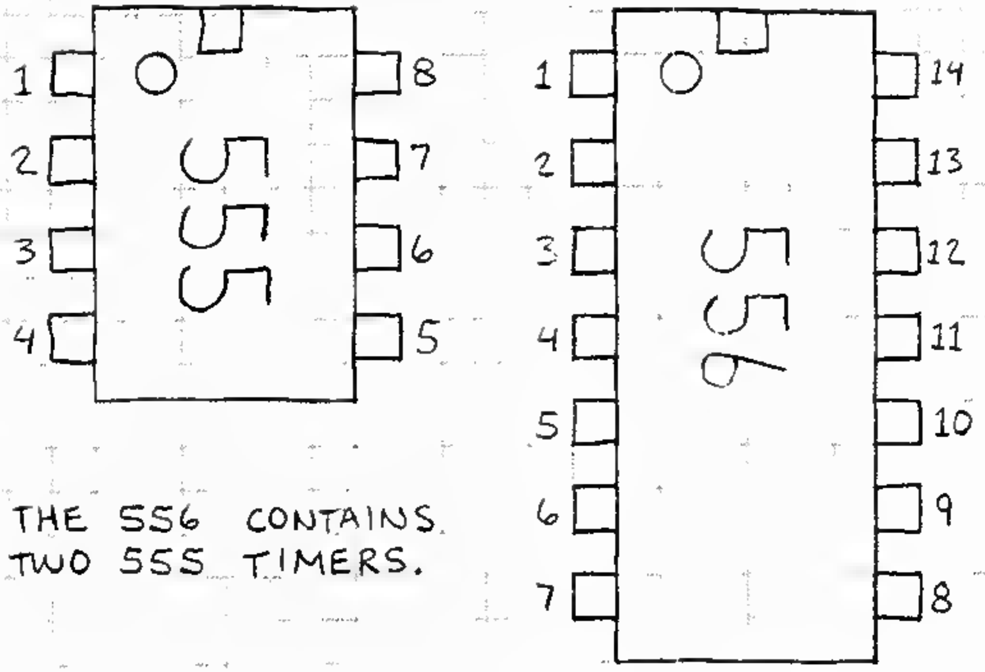
MONOSTABLE MODE - IN THIS MODE THE 555 FUNCTIONS AS A "ONE-SHOT." APPLICATIONS INCLUDE TIMERS, MISSING PULSE DETECTION, BOUNCEFREE SWITCHES, TOUCH SWITCHES, ETC.

ASTABLE MODE - THE 555 CAN OPERATE AS AN OSCILLATOR. USES INCLUDE LED AND LAMP FLASHERS, PULSE GENERATION, LOGIC CLOCKS, TONE GENERATION, SECURITY ALARMS, ETC.

CIRCUIT ASSEMBLY TIPS

BUILD TEST VERSIONS OF YOUR CIRCUITS ON A SOLERLESS BREADBOARD BEFORE MAKING THEM PERMANENT. IN MONOSTABLE CIRCUITS, WHERE FALSE TRIGGERING MIGHT CAUSE PROBLEMS, TIE PIN 5 TO GROUND WITH A 0.1 μF CAPACITOR. IF POWER LEADS ARE LONG, OR IF A CIRCUIT SEEMS TO MALFUNCTION, PLACE A 0.1 μF CAPACITOR ACROSS PINS 8 AND 1. A 1 μF CAPACITOR MAY ALSO BE NECESSARY. BE SURE TO EXPERIMENT WITH VALUES OF TIMING RESISTORS AND CAPACITORS. THE BASIC 555 CIRCUITS EXPLAIN THE ROLE OF THESE COMPONENTS. REMEMBER THAT YOU CAN USE A 556 TO REPLACE TWO 555s. SOME LOW POWER VERSIONS OF THE 555 MAY REQUIRE REVISIONS TO SOME OF THE CIRCUITS IN THIS SECTION.

555/556 PIN OUTLINES



THE 556 CONTAINS TWO 555 TIMERS.

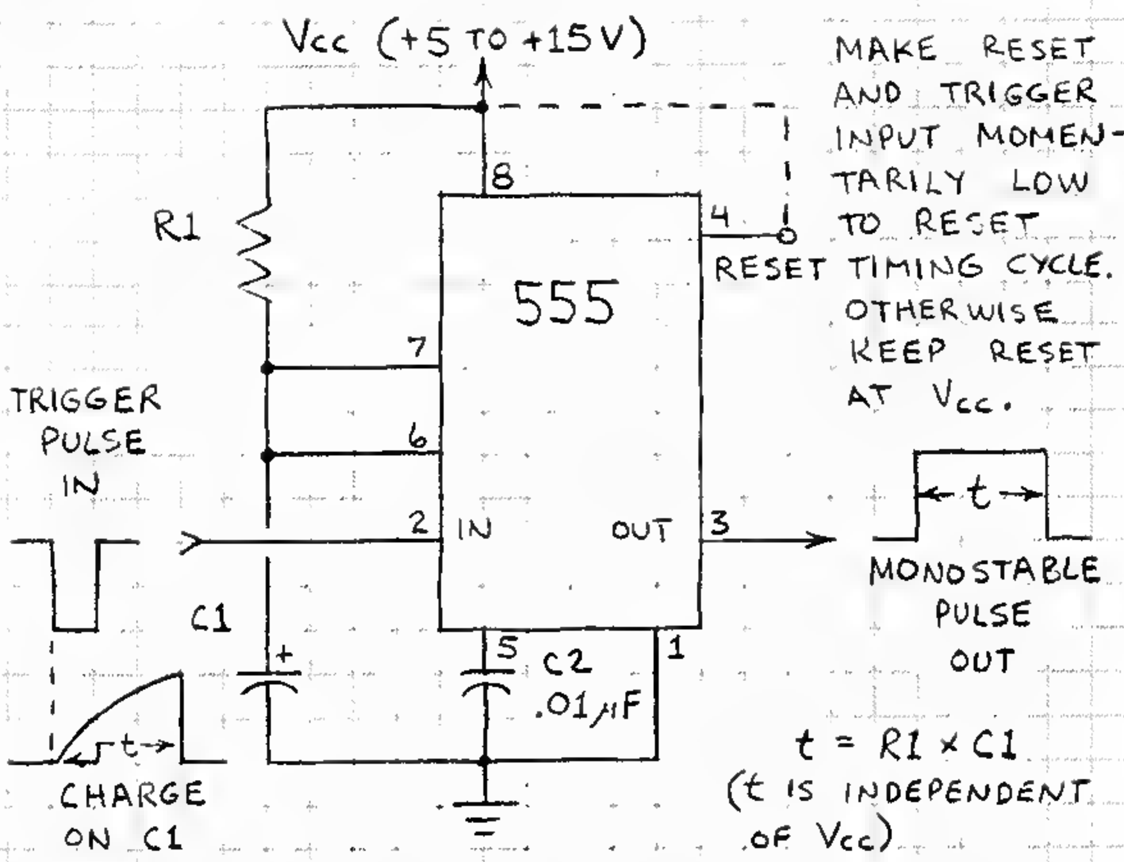
FUNCTION	555	556 (1)	556 (2)
GROUND	1	7	7
TRIGGER	2	6	8
OUTPUT	3	5	9
RESET	4	4	10
CONTROL V	5	3	11
THRESHOLD	6	2	12
DISCHARGE	7	1	13
V_{cc}	8	14	14

555 SPECIFICATIONS[1]

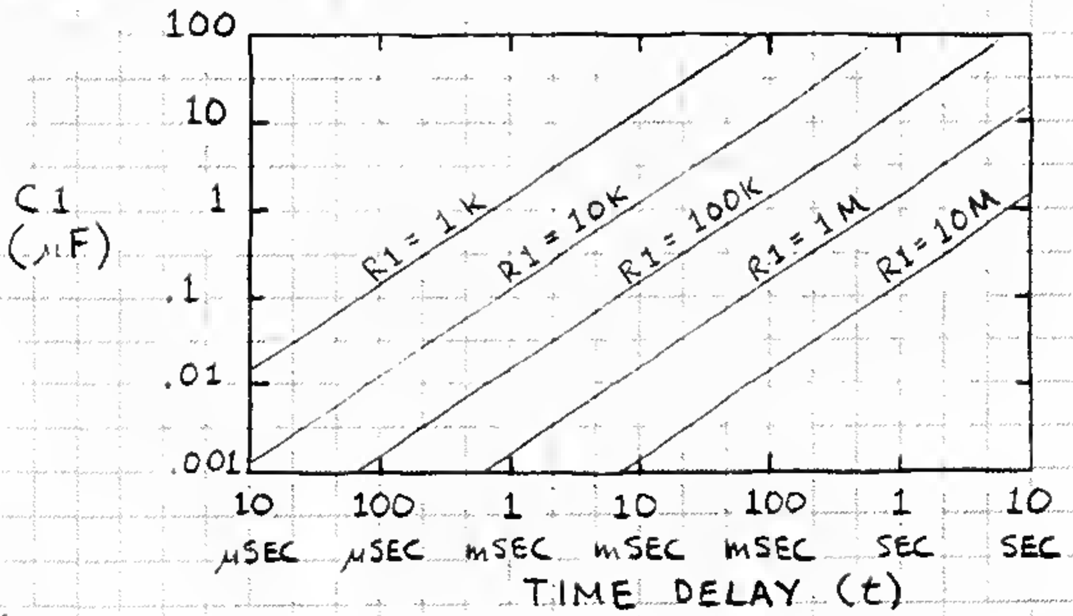
SUPPLY VOLTAGE (V_{cc})	4.5 TO 15 V
SUPPLY CURRENT (V_{cc} = +5V)	3 TO 6 mA
SUPPLY CURRENT (V_{cc} = +15V)	10 TO 15 mA
OUTPUT CURRENT (MAXIMUM)	200 mA
POWER DISSIPATION	600 mW
OPERATING TEMPERATURE	0 TO 70° C

1 VALUES SHOWN APPLY TO NE555.

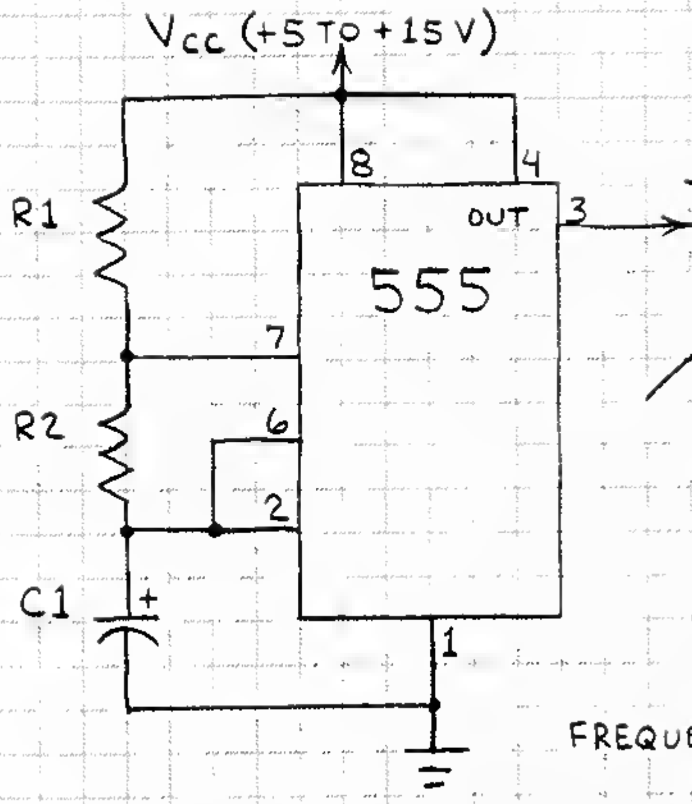
BASIC MONOSTABLE CIRCUIT



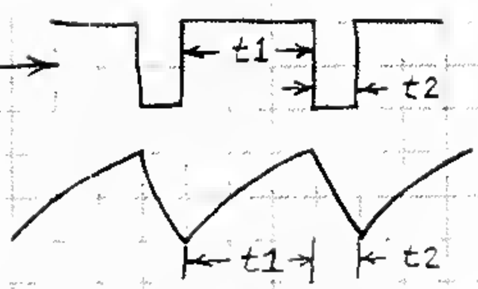
A NEGATIVE TRIGGER PULSE AT PIN 2 TURNS OFF A TRANSISTOR THAT OTHERWISE SHORTS C1 TO GROUND. THE OUTPUT THEN GOES HIGH AS C1 CHARGES THROUGH R1. WHEN THE CHARGE ON C1 IS 2/3 Vcc, THE 555 DISCHARGES C1 TO GROUND. THE OUTPUT THEN GOES LOW.



BASIC ASTABLE CIRCUIT



OUTPUT PULSES



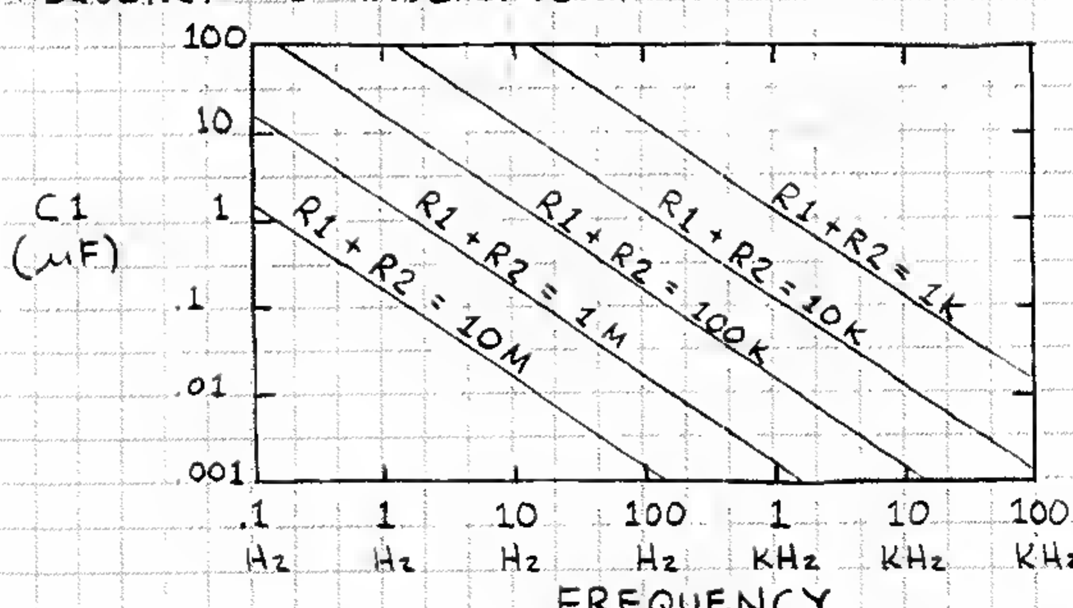
CHARGE ON C1

$$t1 = .693\,(R1 + R2)\,C1$$

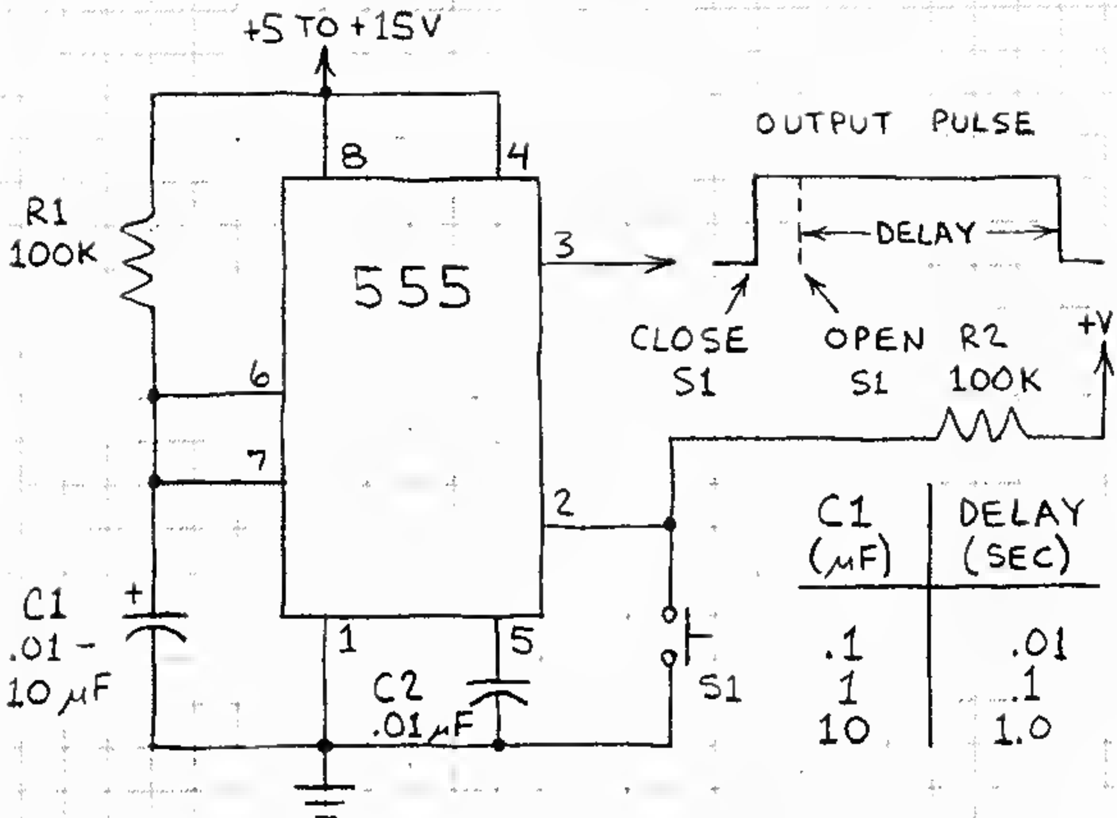
$$t2 = .693\,(R2)\,C1$$

$$\text{FREQUENCY} = \frac{1.44}{(R1 + 2\,R2)\,C1}$$

HERE PINS 2 AND 6 ARE CONNECTED SO THE CIRCUIT WILL TRIGGER ITSELF EACH TIMING CYCLE, THEREBY FUNCTIONING AS AN OSCILLATOR. C1 CHARGES THROUGH R1 AND R2 BUT DISCHARGES THROUGH R2. THE CHARGE ON C1 RANGES FROM 1/3 Vcc TO 2/3 Vcc. THE OSCILLATION FREQUENCY IS INDEPENDENT OF Vcc.

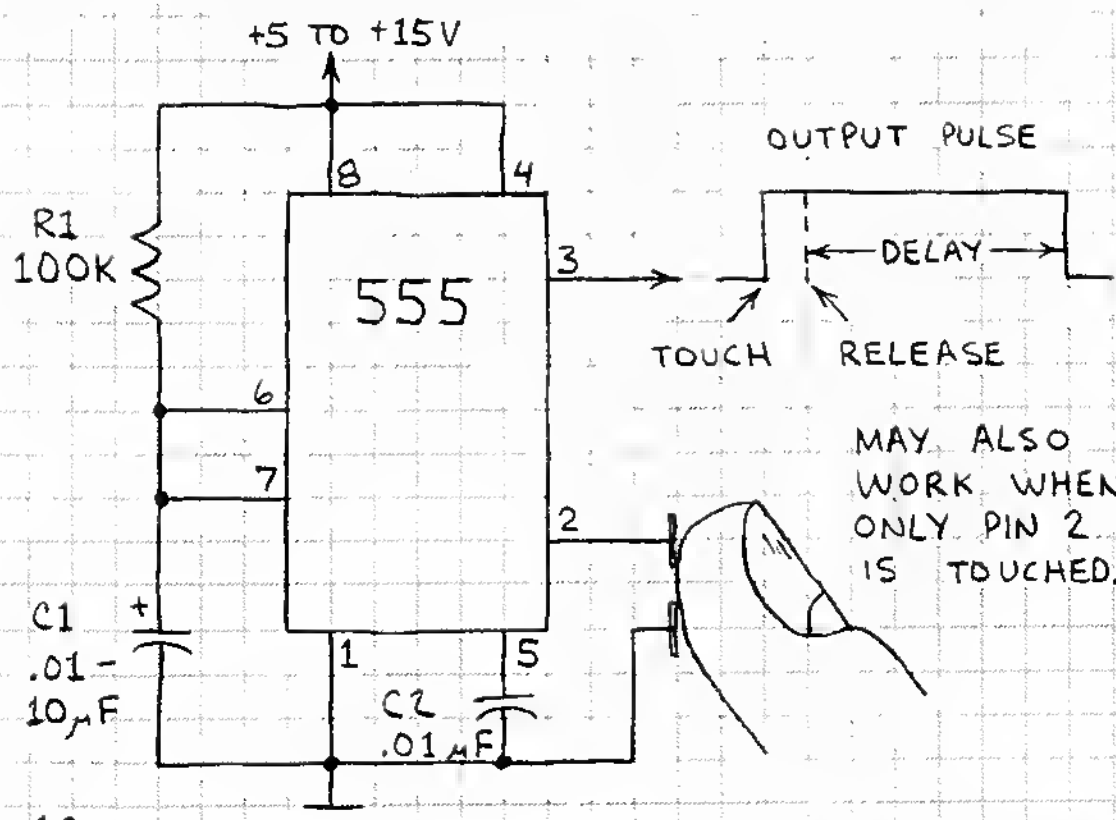


BOUNCEFREE SWITCH

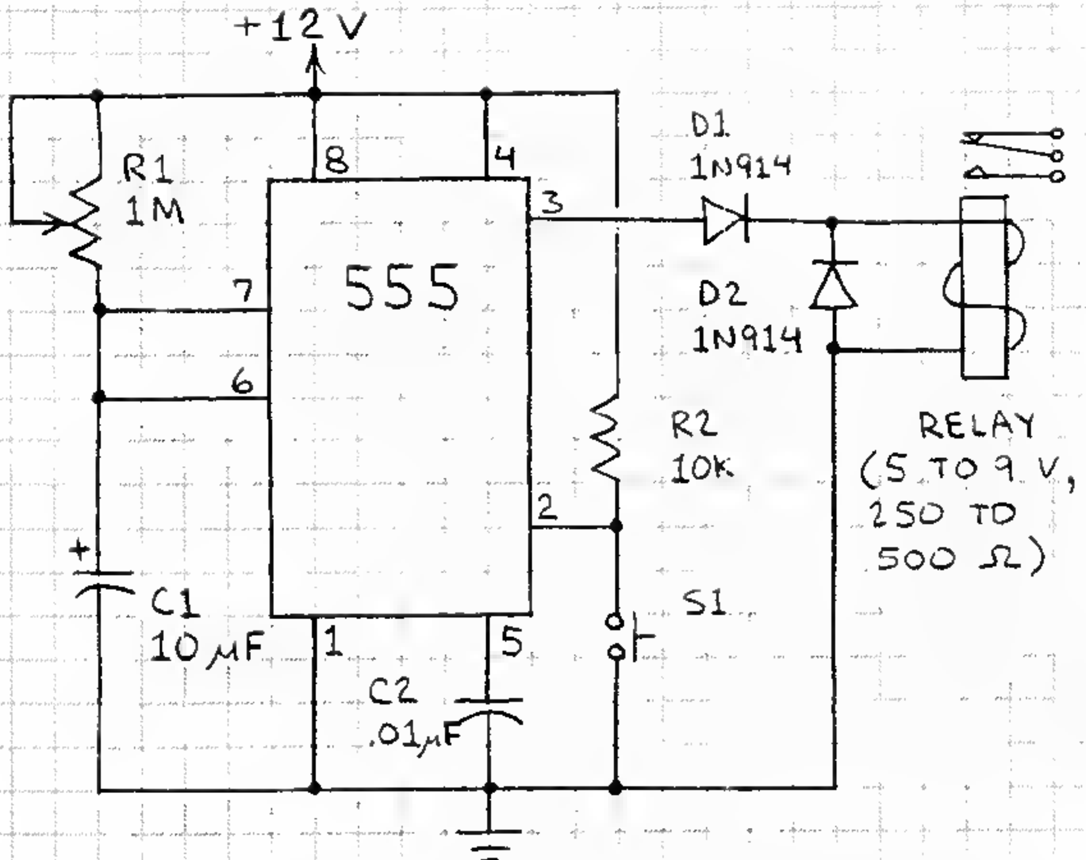


C1 (μF)	DELAY (SEC)
.1	.01
1	.1
10	1.0

TOUCH-ACTIVATED SWITCH



TIMER PLUS RELAY

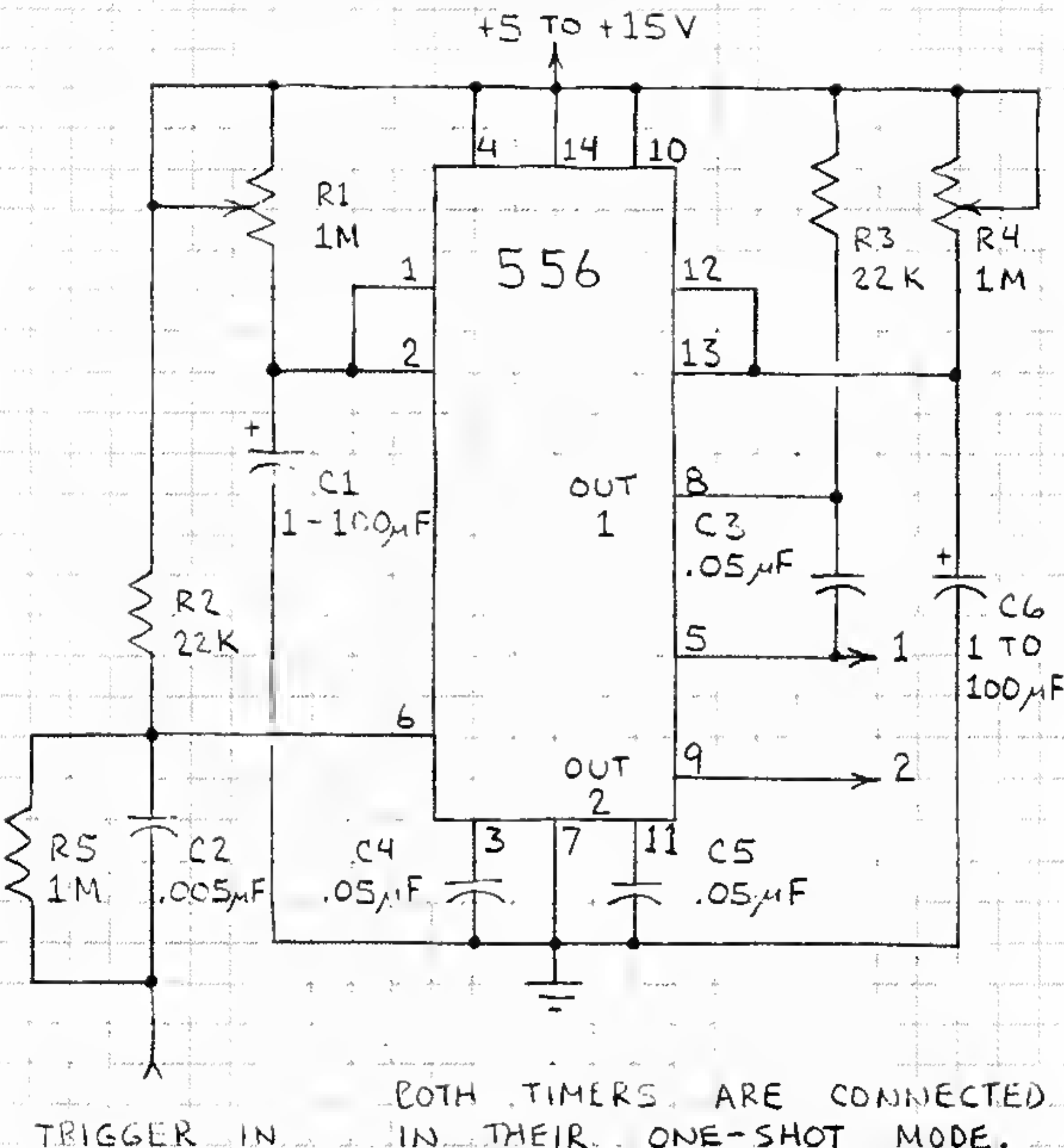


CLOSING S1 MOMENTARILY BEGINS A TIMING CYCLE. THE RELAY IS ACTUATED DURING THE ENTIRE CYCLE. R1 AND C1 CONTROL TIME DELAY. C2 PREVENTS FALSE TRIGGERING. D2 ABSORBS VOLTAGE GENERATED BY RELAY COIL WHEN RELAY IS SWITCHED OFF. USE CAUTION WHEN CONNECTING LINE-POWERED DEVICES TO RELAY CONNECTIONS.

TYPICAL DELAYS (SECONDS)

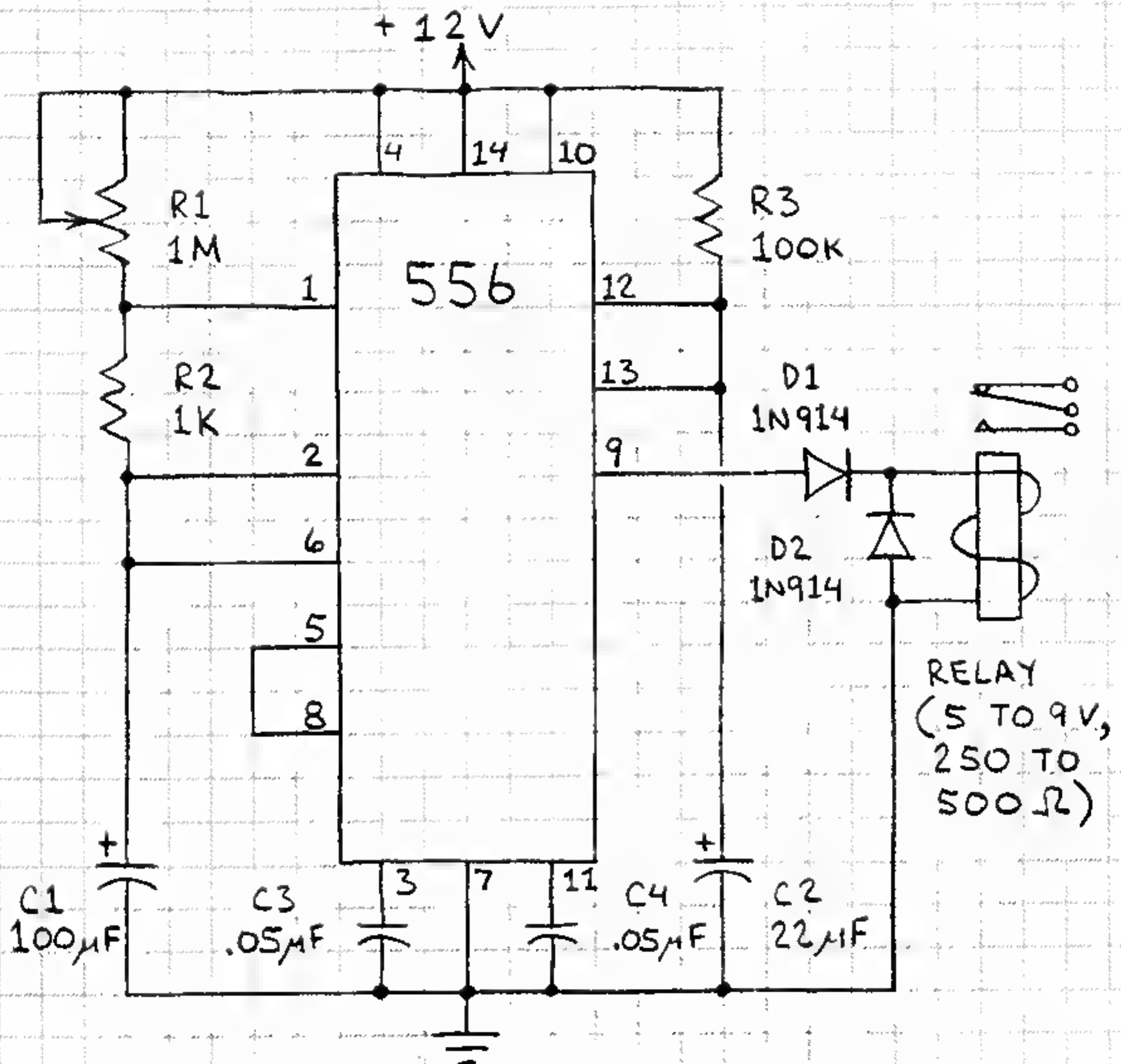
R1	C1 = 10 µF	C1 = 100 µF
100K	2	16
220K	3	33
470K	6	70
1M	15	175

CASCADED TIMER

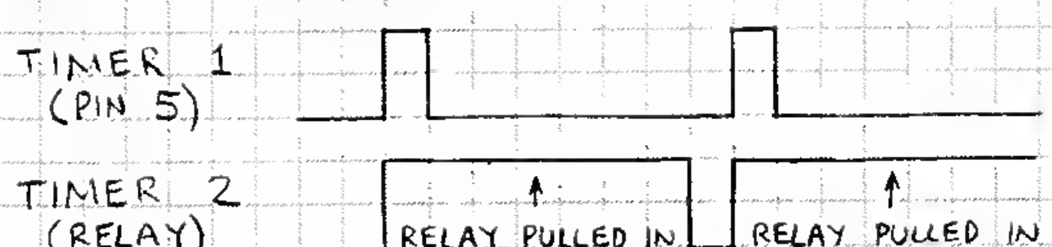


BOTH TIMERS ARE CONNECTED IN THEIR ONE-SHOT MODE. GROUNDING THE TRIGGER INPUT STARTS TIMER 1 WHICH THEN STARTS TIMER 2.

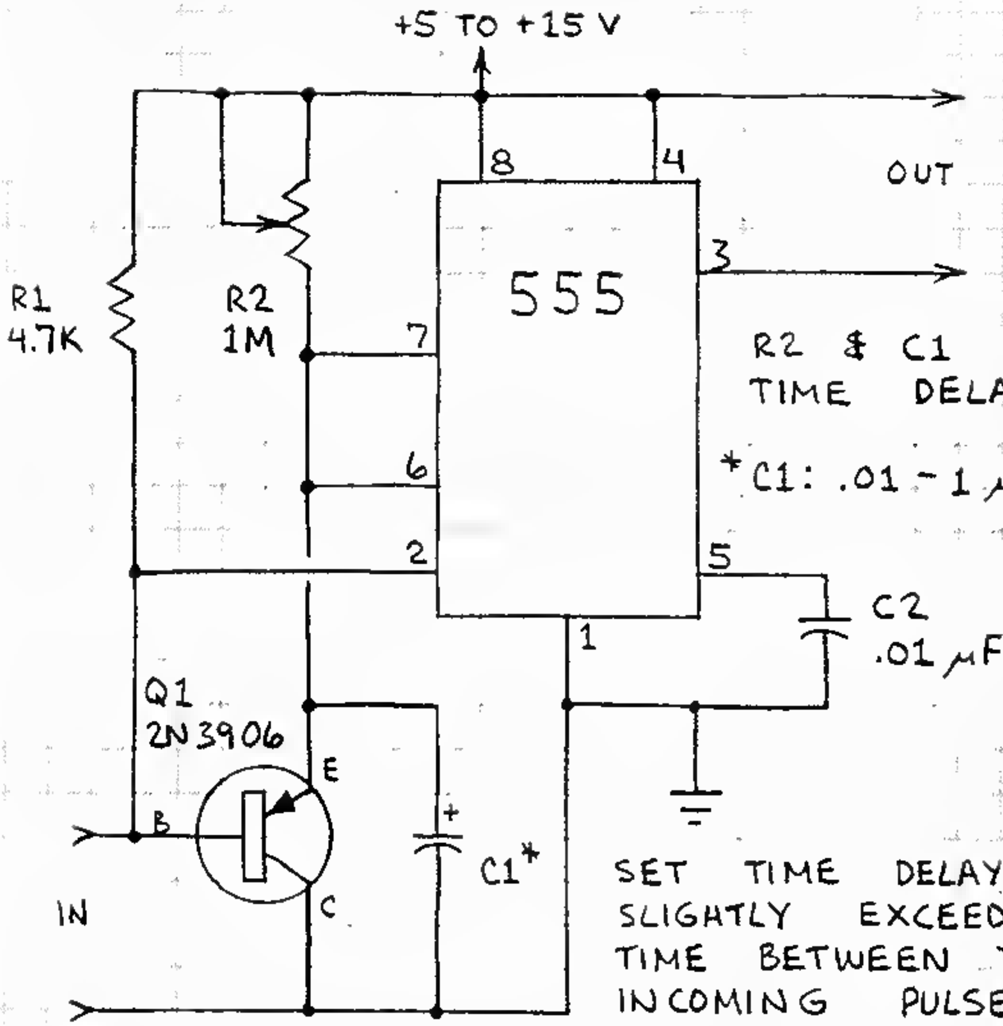
INTERVALOMETER



TIMER 1 IS CONNECTED AS ASTABLE OSCILLATOR WHICH OSCILLATES AT A FREQUENCY DETERMINED BY R1 AND C1. TIMER 2 IS A ONE-SHOT THAT DRIVES A RELAY VIA D1. TIMER 1 TRIGGERS TIMER 2 ONCE PER CYCLE FOR 3 TO 5 SECONDS.



MISSING PULSE DETECTOR

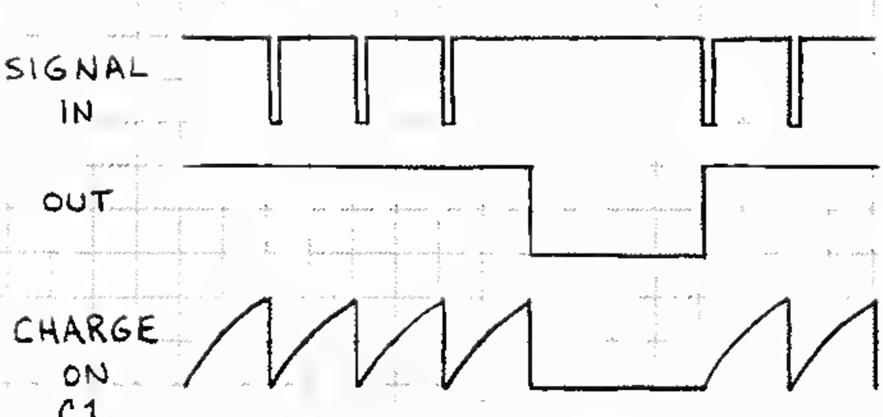


R2 & C1 SET TIME DELAY.

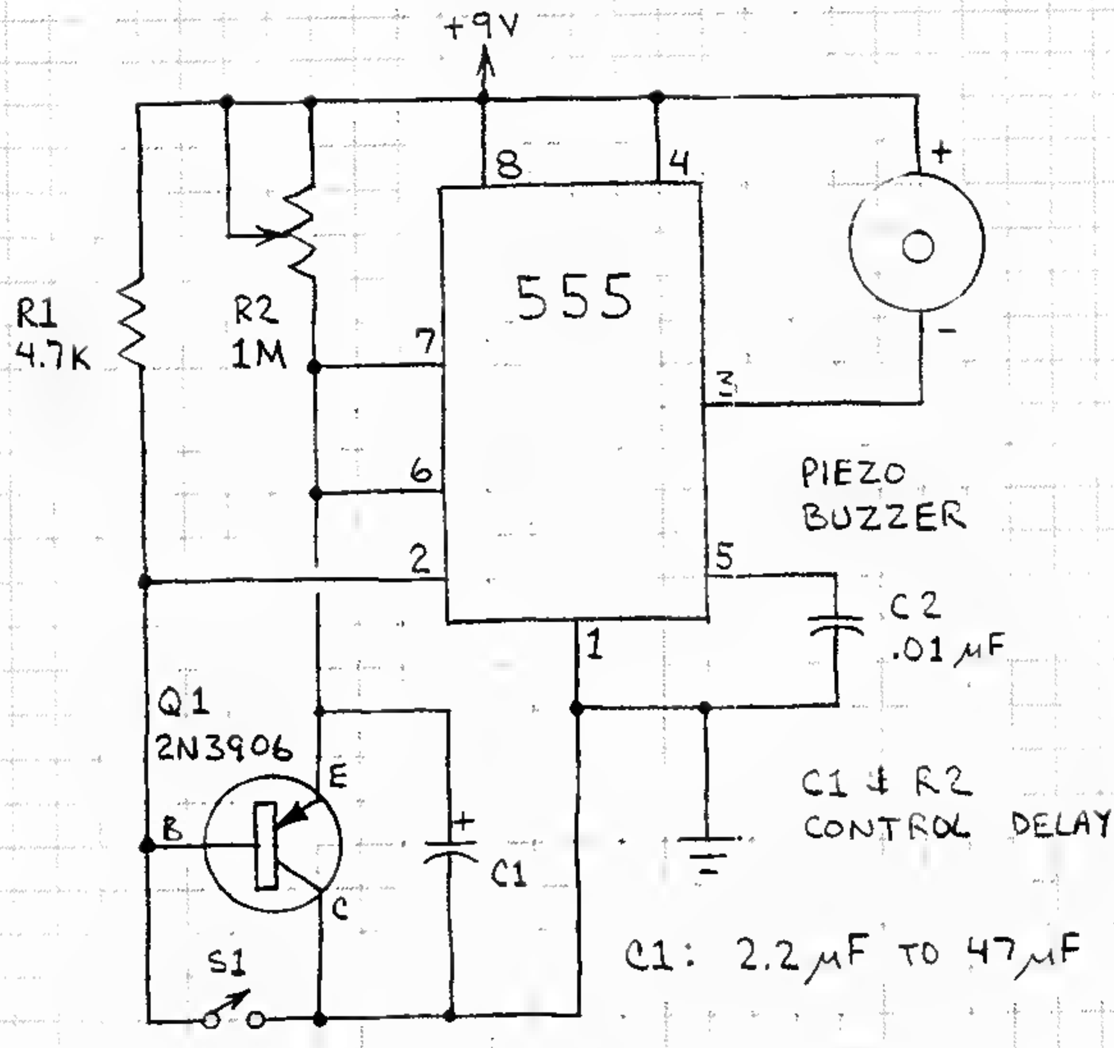
*C1: .01 - 1 µF

SET TIME DELAY TO SLIGHTLY EXCEED TIME BETWEEN THE INCOMING PULSES.

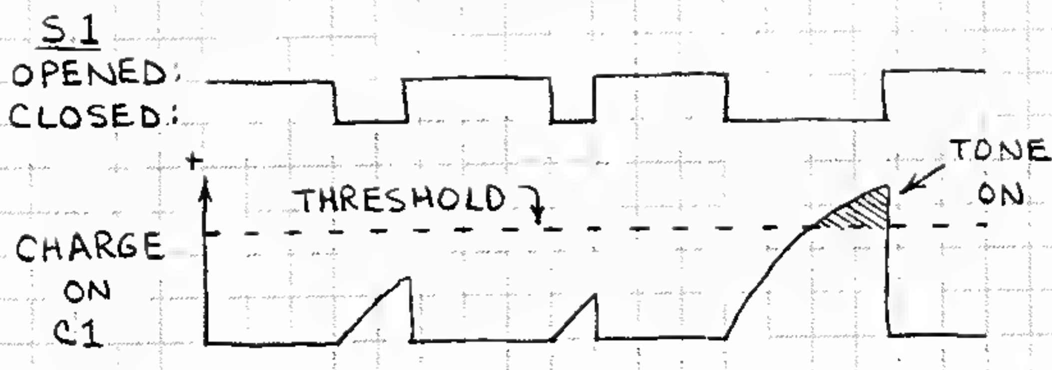
INCOMING PULSES CONTINUALLY RESET THE TIMING CYCLE. A MISSING PULSE ALLOWS THE TIMING CYCLE TO BE COMPLETED, CHANGING THE OUTPUT STATE.



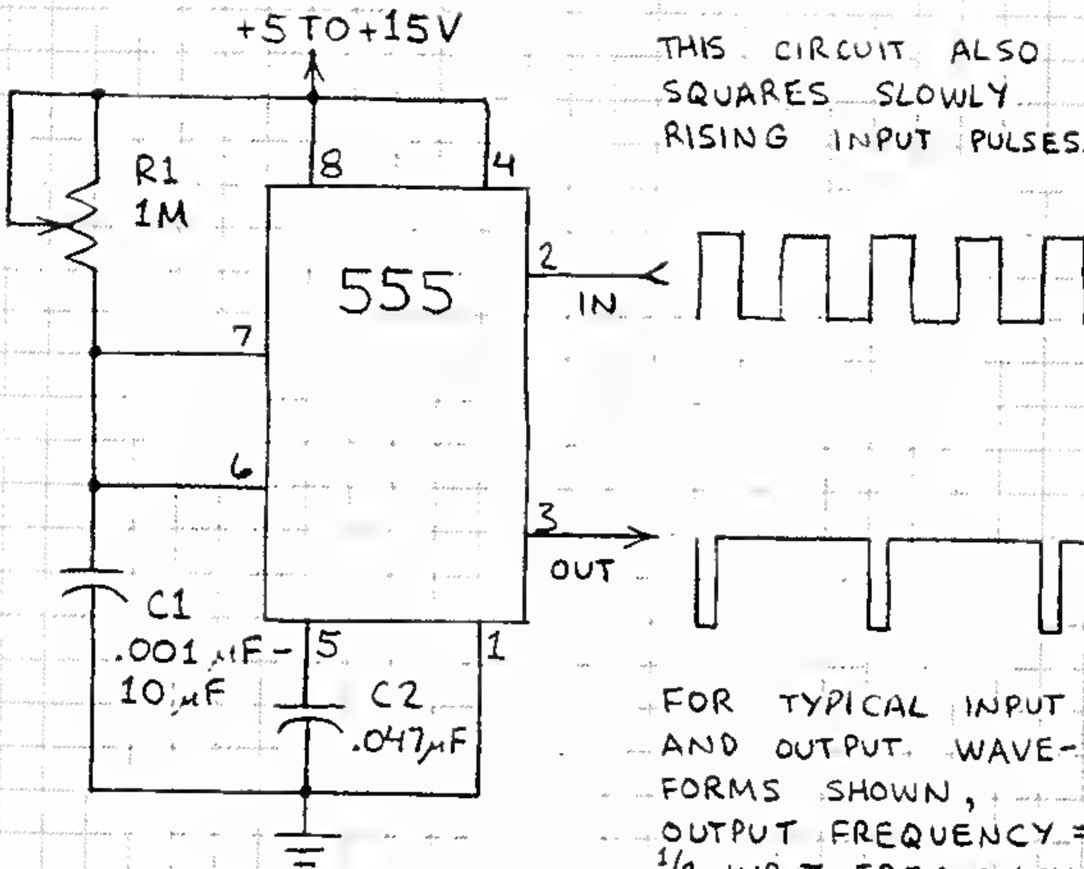
EVENT FAILURE ALARM



WHEN POWER IS APPLIED, C1 BEGINS TO CHARGE THROUGH R2. UNLESS S1 IS CLOSED <u>BEFORE</u> THE 555 TIMING CYCLE IS COMPLETED, THE BUZZER WILL SOUND. S1 CAN BE ANY EXTERNAL SWITCH.



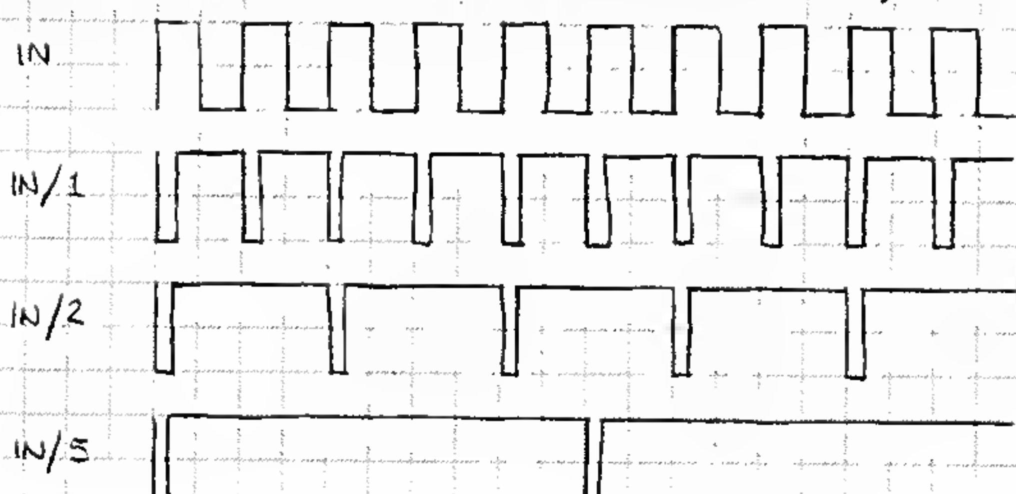
FREQUENCY DIVIDER



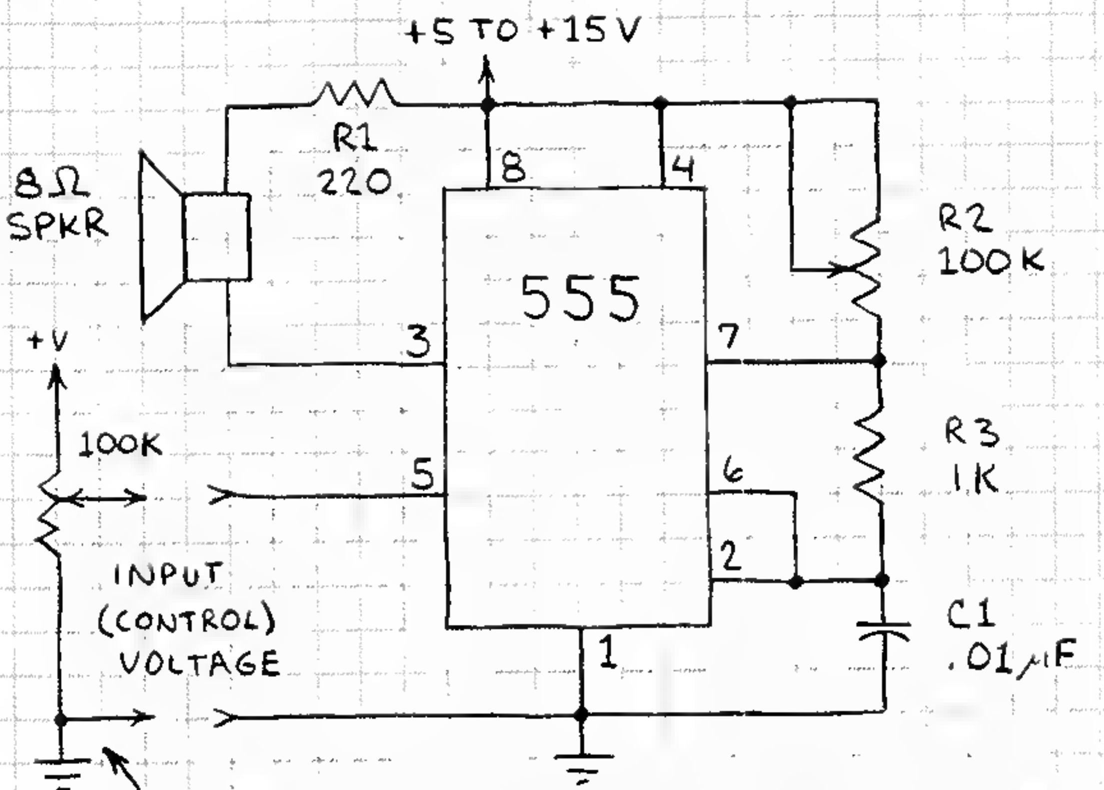
THIS CIRCUIT ALSO SQUARES SLOWLY RISING INPUT PULSES.

FOR TYPICAL INPUT AND OUTPUT WAVEFORMS SHOWN, OUTPUT FREQUENCY = 1/2 INPUT FREQUENCY.

IN THIS CIRCUIT THE 555 IS CONNECTED AS A MONOSTABLE MULTIVIBRATOR. ONCE A TIMING CYCLE IS INITIATED BY AN INPUT PULSE, SUBSEQUENT INPUT PULSES HAVE NO EFFECT UNTIL CYCLE IS COMPLETED. SHOWN BELOW ARE TYPICAL INPUT AND OUTPUT WAVEFORMS (C1 = 0.1 μF, R1 VARIED IN VALUE).

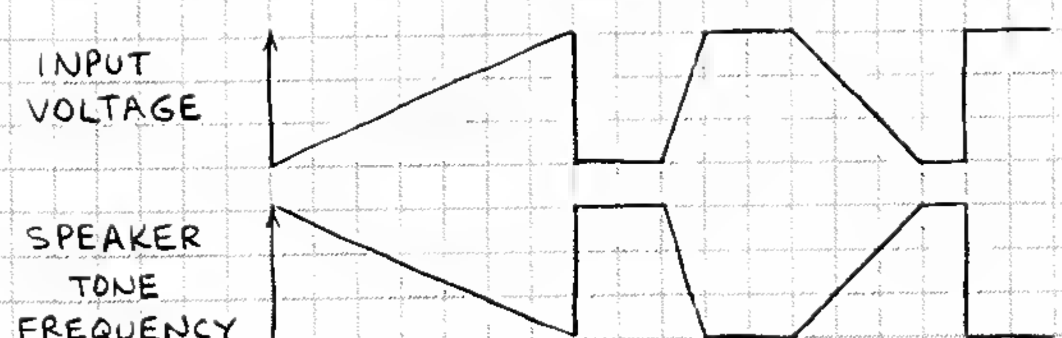


VOLTAGE-CONTROLLED OSCILLATOR

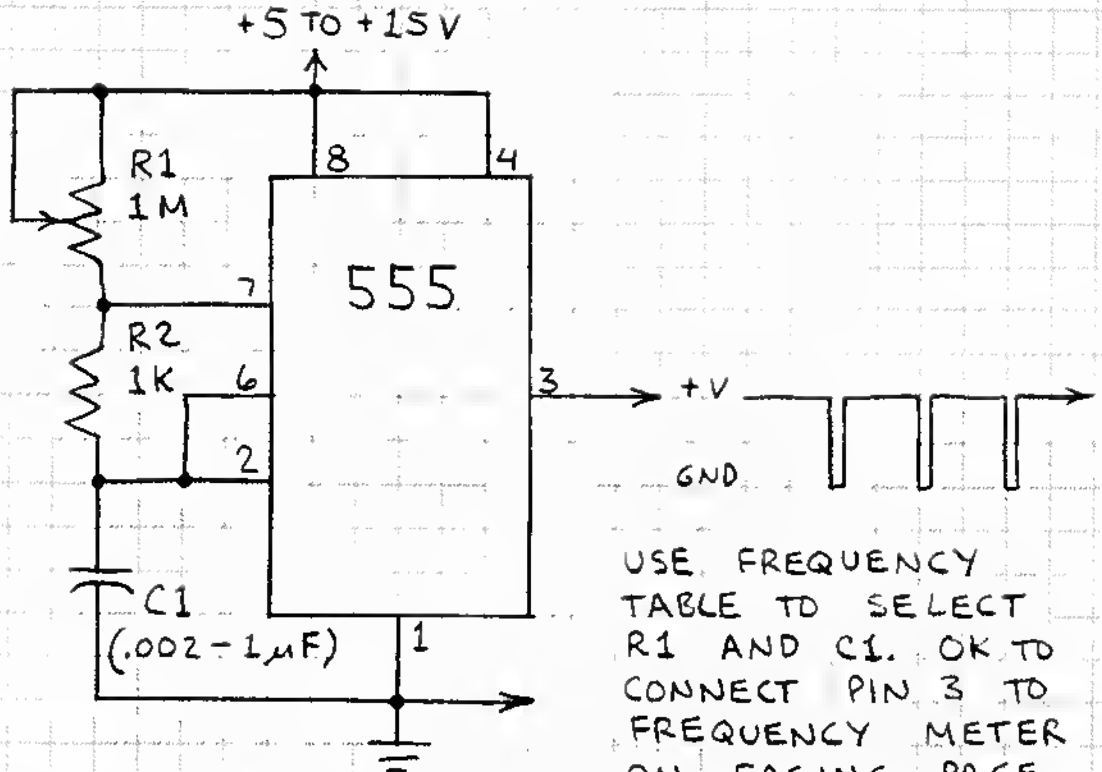


USE TO PROVIDE VARIABLE INPUT VOLTAGE WHEN TESTING CIRCUIT.

THE 555 OSCILLATES AT A FREQUENCY DETERMINED BY R2 AND C1. A VOLTAGE APPLIED TO THE INPUT CHANGES THE OSCILLATION FREQUENCY OF THE 555. AS THE INPUT VOLTAGE INCREASES, THE OSCILLATION FREQUENCY DECREASES. FOR MORE VOLUME, OMIT R1 AND CONNECT SPKR TO GROUND THROUGH 4.7µF CAPACITOR.



PULSE GENERATOR



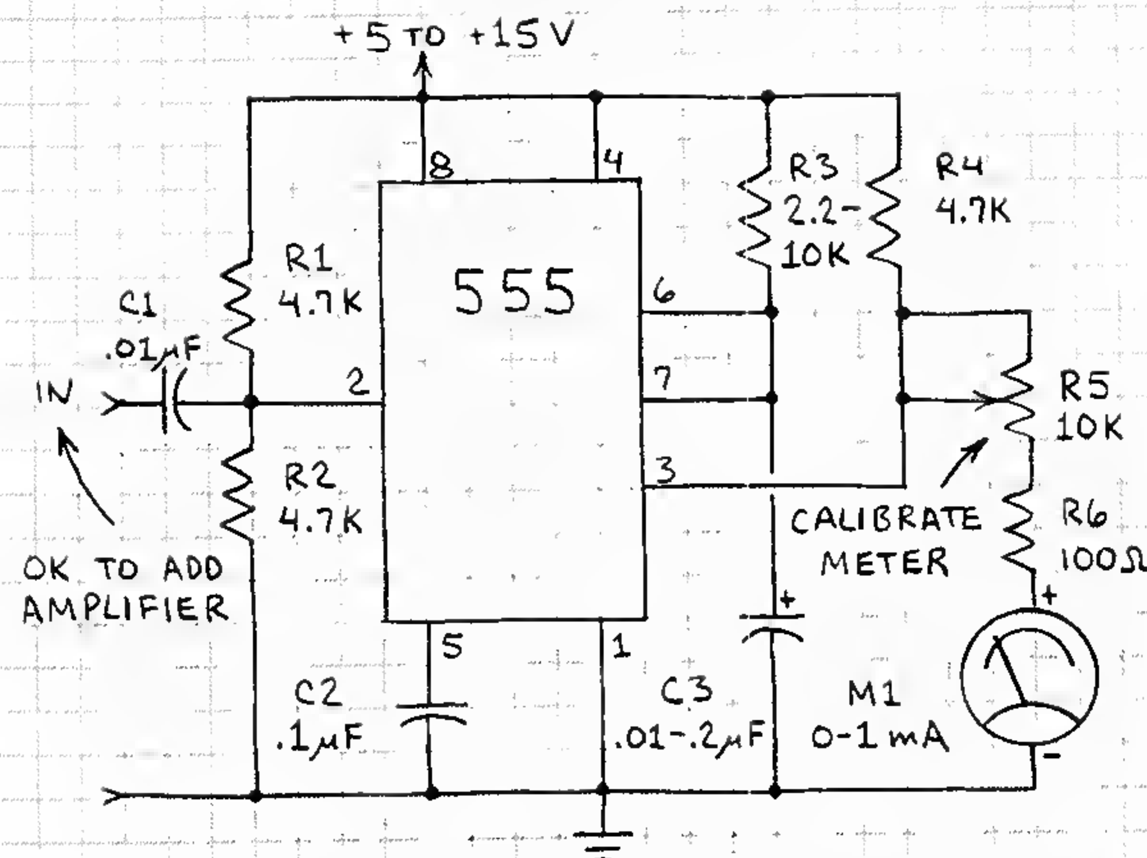
USE FREQUENCY TABLE TO SELECT R1 AND C1. OK TO CONNECT PIN 3 TO FREQUENCY METER ON FACING PAGE.

USE AS DIGITAL LOGIC CLOCK PULSE GENERATOR, SIGNAL GENERATOR, ETC.

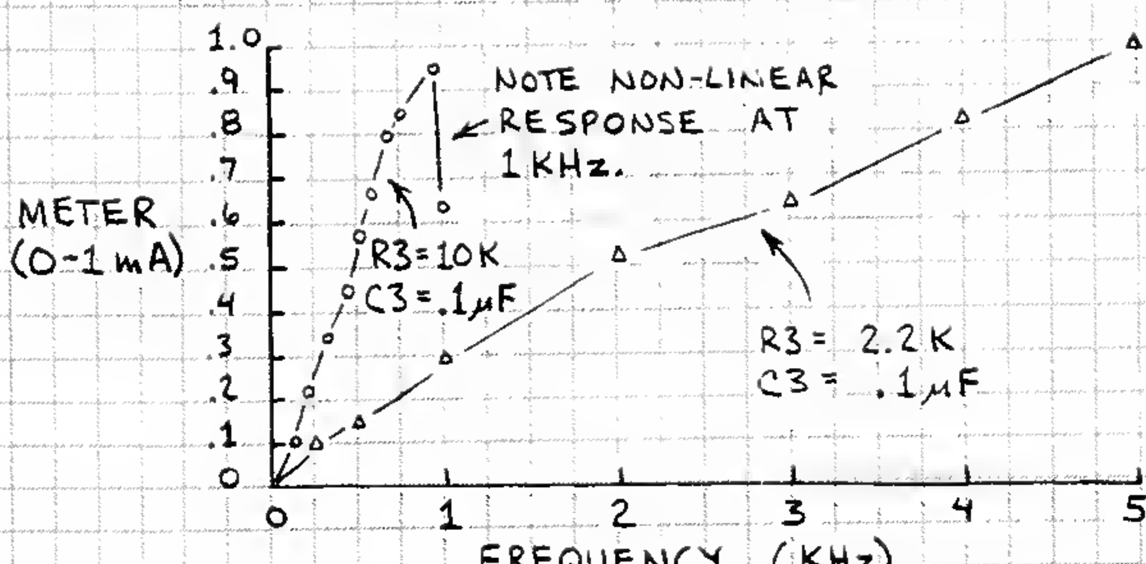
FREQUENCY TABLE (FREQUENCIES IN Hz)

C1 (μF)	R1 = 10K	R1 = 100K	R1 = 1M
.0022	42,470	5,240	520
.0033	30,490	3,740	371
.0047	21,522	2,630	261
.0068	16,300	1,987	197
.01	11,622	1,414	140
.015	7,210	876	87
.022	4,959	601	60
.033	3,530	428	42
.047	2,351	285	28
.068	1,737	210	20
.1	1,139	138	14
.15	804	97	10
.22	540	65	6

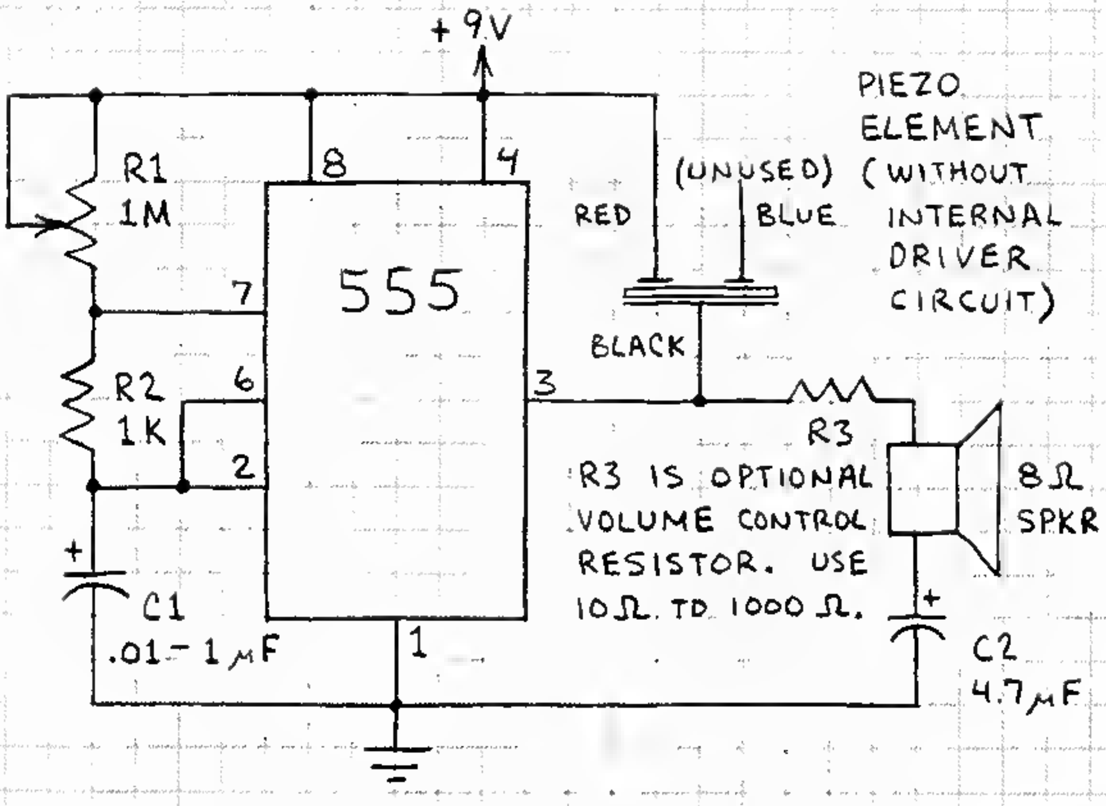
FREQUENCY METER



THIS ULTRA-SIMPLE CIRCUIT MEASURES AUDIO FREQUENCY SIGNALS. INPUT SIGNAL SHOULD RANGE FROM 2.5 TO 5 VOLTS. FOR TESTING, CONNECT PULSE GENERATOR ON FACING PAGE DIRECTLY TO PIN 2 (OMIT C1). R3 AND C3 DETERMINE FREQUENCY RANGE.



AUDIO OSCILLATOR / METRONOME



THIS CIRCUIT WILL FUNCTION WITH EITHER OR BOTH OUTPUT DEVICES. THE SPEAKER GIVES MORE VOLUME, BUT USES MORE CURRENT. USE R3 TO REDUCE VOLUME. HERE ARE TYPICAL FREQUENCIES FOR VARIOUS SETTINGS OF R1:

OSCILLATOR (C = .01 μF)

R1	FREQUENCY (Hz)
1M	17
470K	40
220K	85
100K	177
47K	410
22K	838
10K	1570
4.7K	2746
2.2K	4606
1K	6283

METRONOME (C1 = 1 μF)

R1	FREQUENCY (Hz)
1M	1.2
680K	1.8
470K	2.9
220K	6.1
100K	9.4

NOTE: YOUR VALUES MAY VARY.

(4.7K – 1K:) PIEZO GIVES INTENSE SOUND.

TOY ORGAN

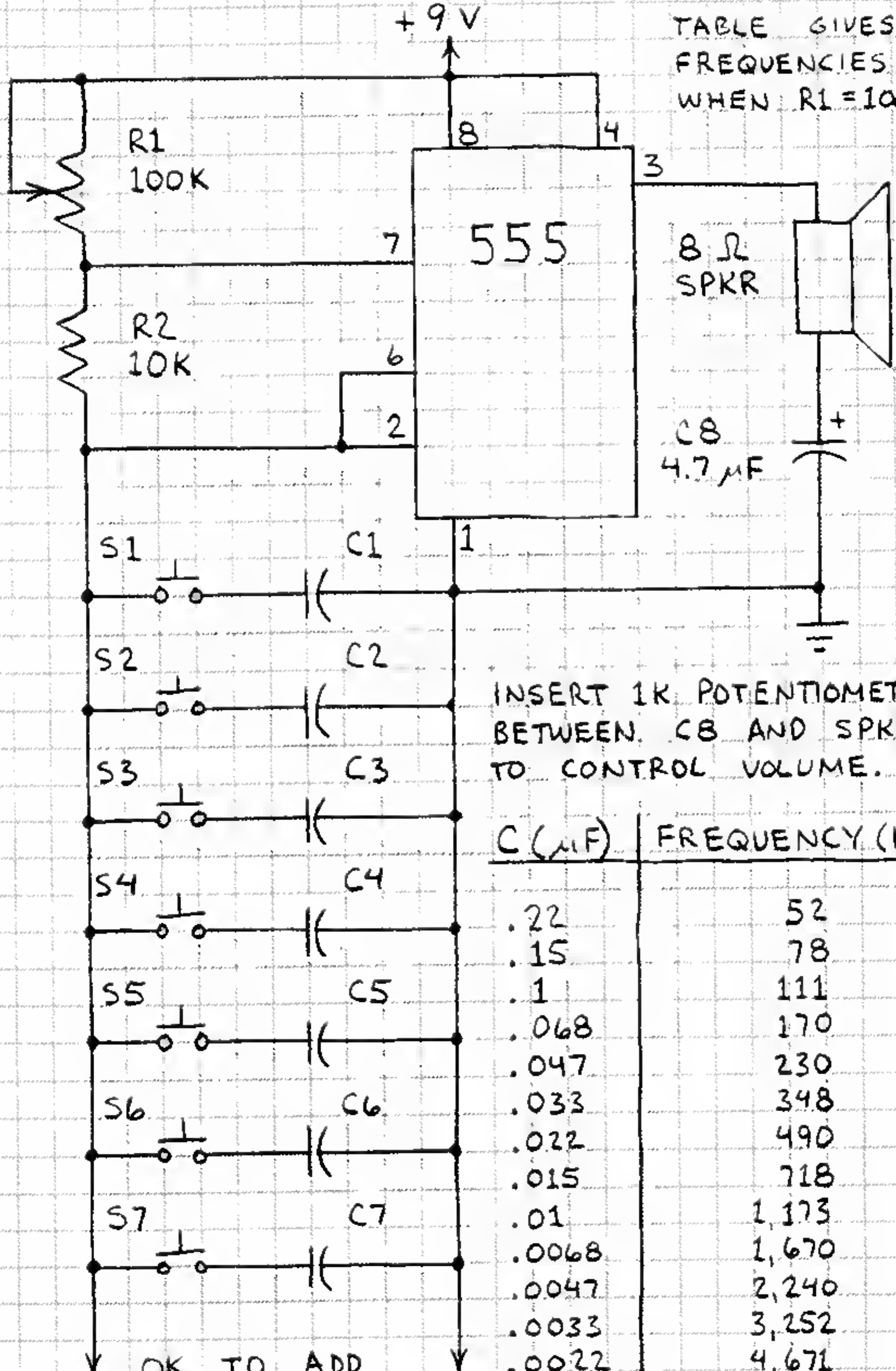


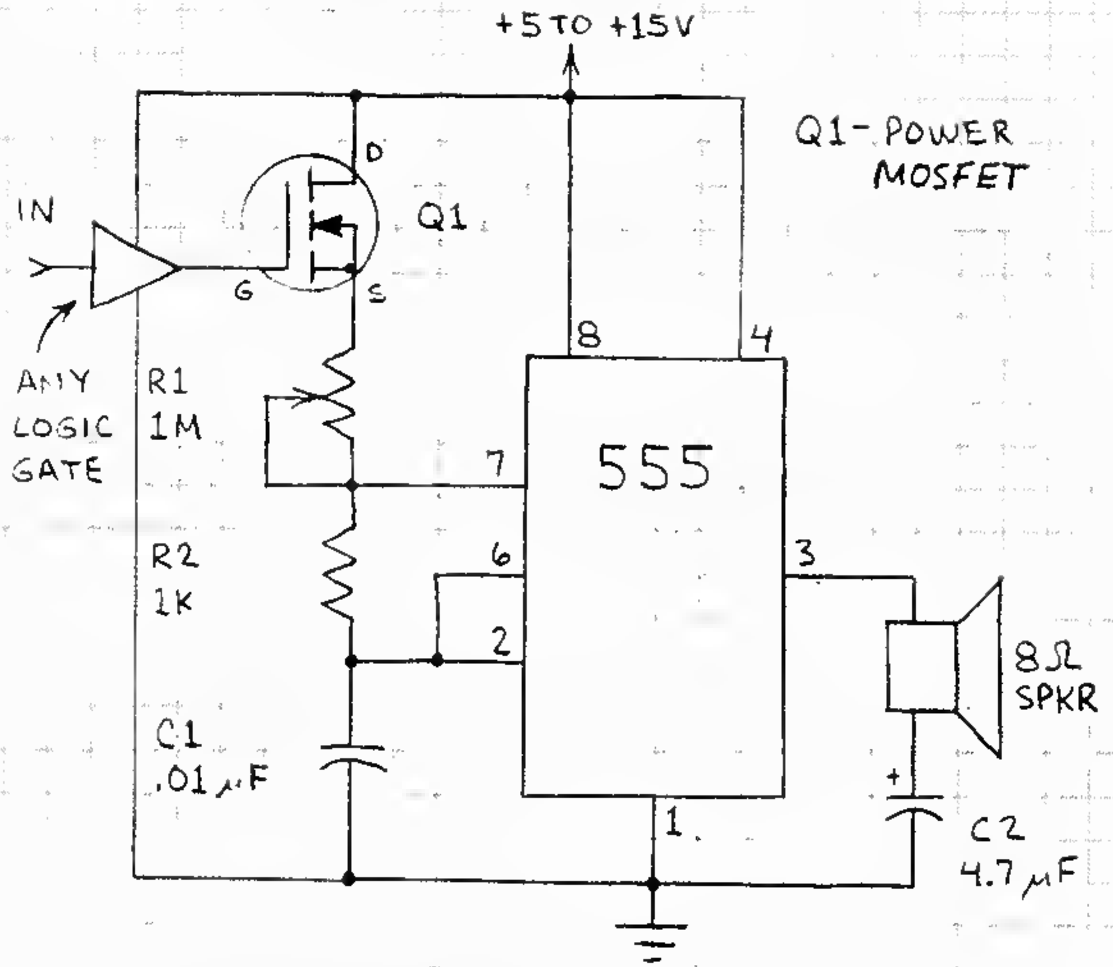
TABLE GIVES FREQUENCIES WHEN R1 = 100K.

INSERT 1K POTENTIOMETER BETWEEN C8 AND SPKR TO CONTROL VOLUME.

OK TO ADD ADDITIONAL CAPACITORS.

C (μF)	FREQUENCY (Hz)
.22	52
.15	78
.1	111
.068	170
.047	230
.033	348
.022	490
.015	718
.01	1,173
.0068	1,670
.0047	2,240
.0033	3,252
.0022	4,671
.0015	6,336
.001	9,237

GATED OSCILLATOR

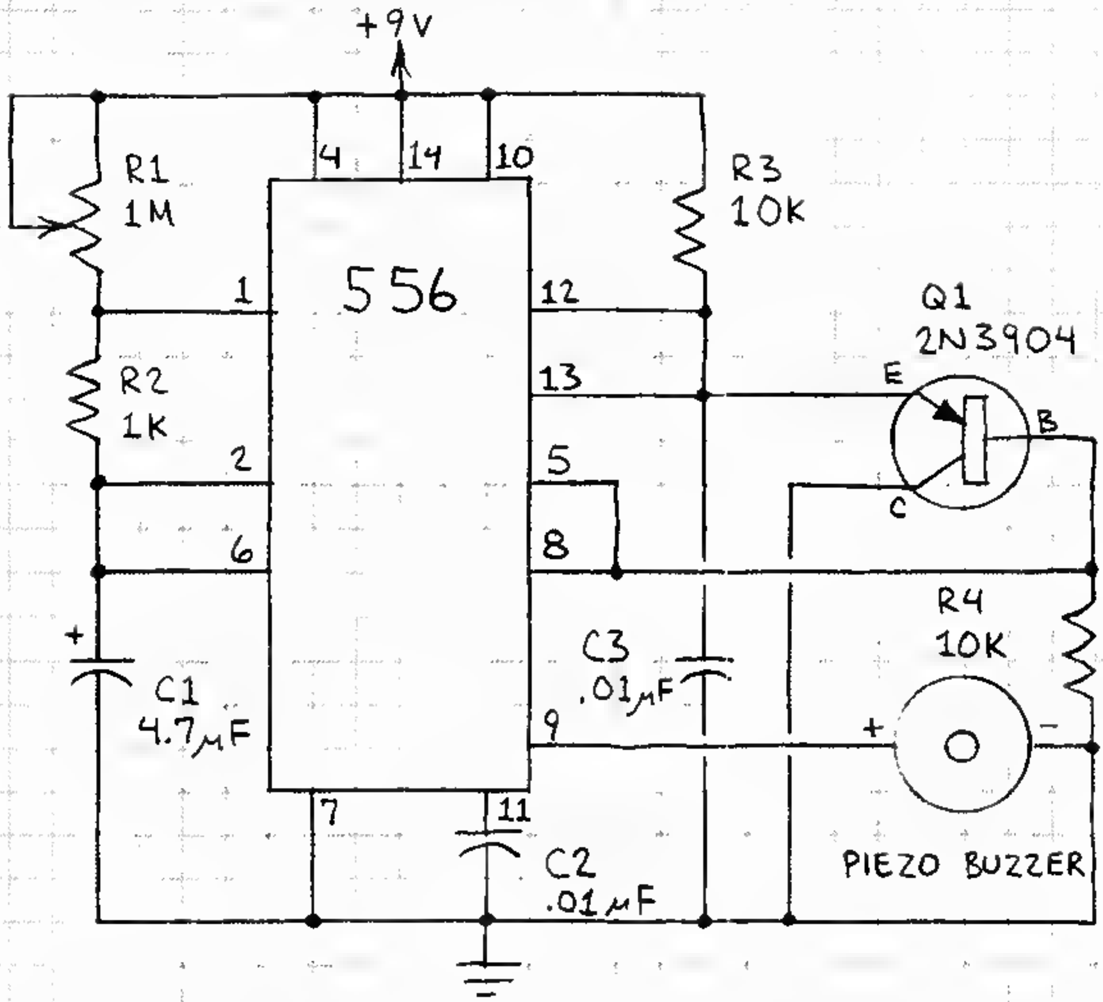


THIS CIRCUIT WILL ALLOW YOU TO SWITCH THE TONE GENERATED BY THE 555 BY MEANS OF AN EXTERNAL LOGIC SIGNAL. THE TRIANGULAR SYMBOL IS ANY EXTERNAL LOGIC GATE. OK TO SWITCH THE TONE ON AND OFF BY CONNECTING GATE OF Q1 TO +V OR GROUND THROUGH 1M RESISTOR. R1 AND C1 CONTROL TONE FREQUENCY. Q1 CAN BE CONNECTED AS A SWITCHABLE GATE ELSEWHERE IN CIRCUIT.

IN	TONE
LOW	OFF
HIGH	ON

CAUTION: Q1 CAN BE DESTROYED BY STATIC ELECTRICITY! DO NOT TOUCH EXPOSED LEADS. FOLLOW HANDLING PRECAUTIONS ON PACKAGE.

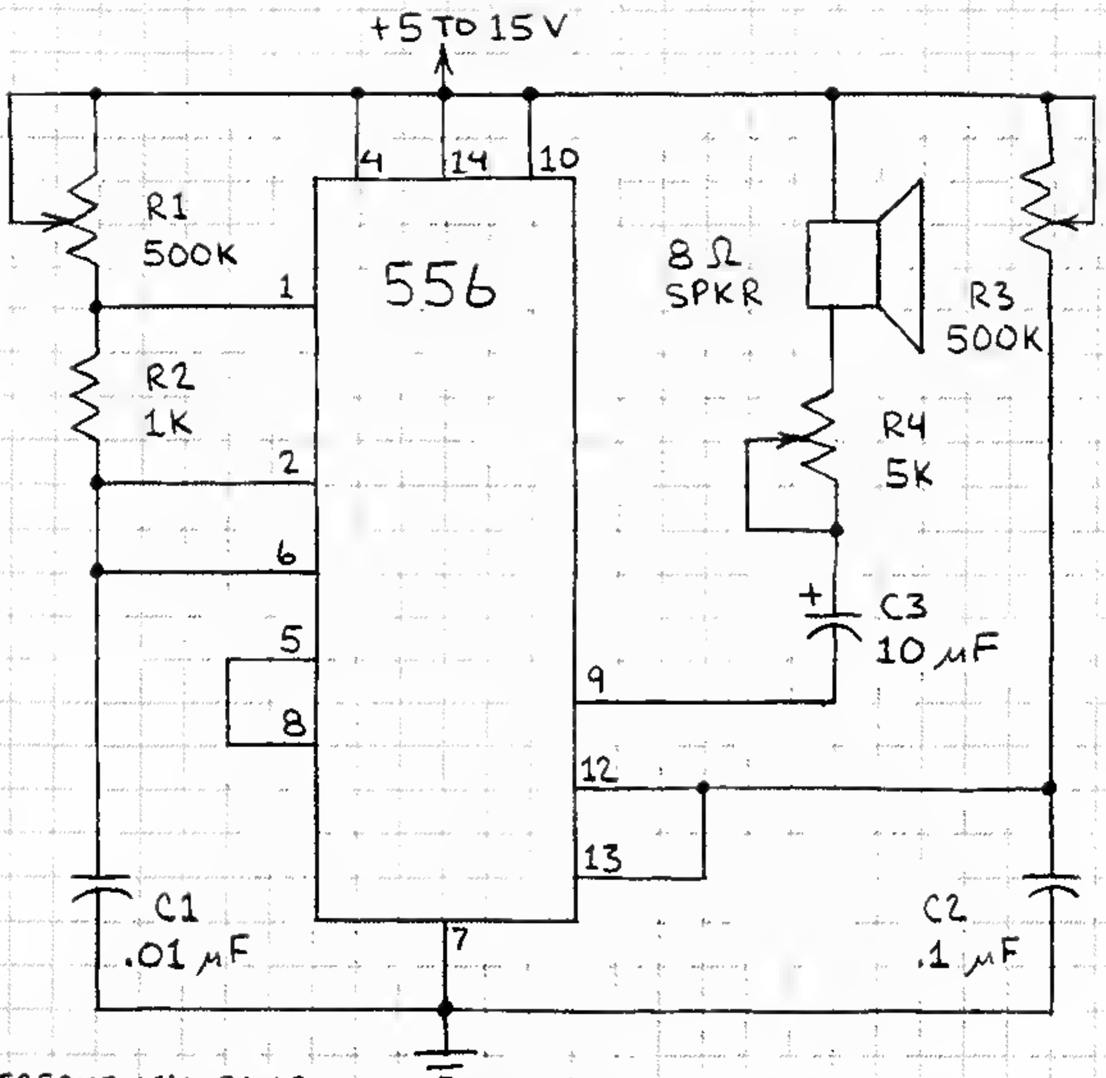
CHIRP GENERATOR



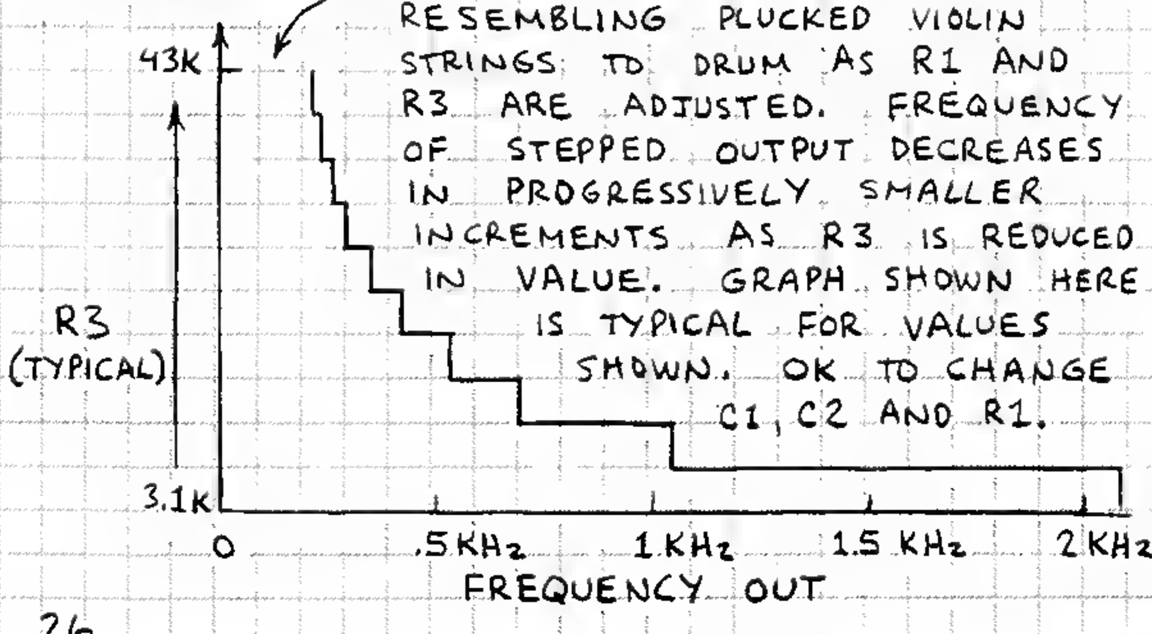
THIS CIRCUIT APPLIES BRIEF PULSES OF CURRENT TO A PIEZO BUZZER (RADIO SHACK 273-065 OR SIMILAR). THIS CAUSES THE BUZZER TO EMIT ATTENTION-GETTING CHIRPS. THE CIRCUIT MAKES A GOOD WARNING DEVICE.

R1 CONTROLS RATE OF CHIRPS. USE 100K FIXED RESISTOR FOR ABOUT 2-3 CHIRPS PER SECOND. C3 CONTROLS DURATION OF CHIRPS. FOR LONG DURATION PULSES (WHICH BECOME TONE BURSTS) INCREASE C3 TO 0.22 μF OR MORE. REDUCE VOLUME BY INSERTING 100 – 10,000 Ω RESISTOR BETWEEN PIN 9 AND PIEZO BUZZER. TRY USING CdS PHOTORESISTOR FOR R1.

STEPPED-TONE GENERATOR

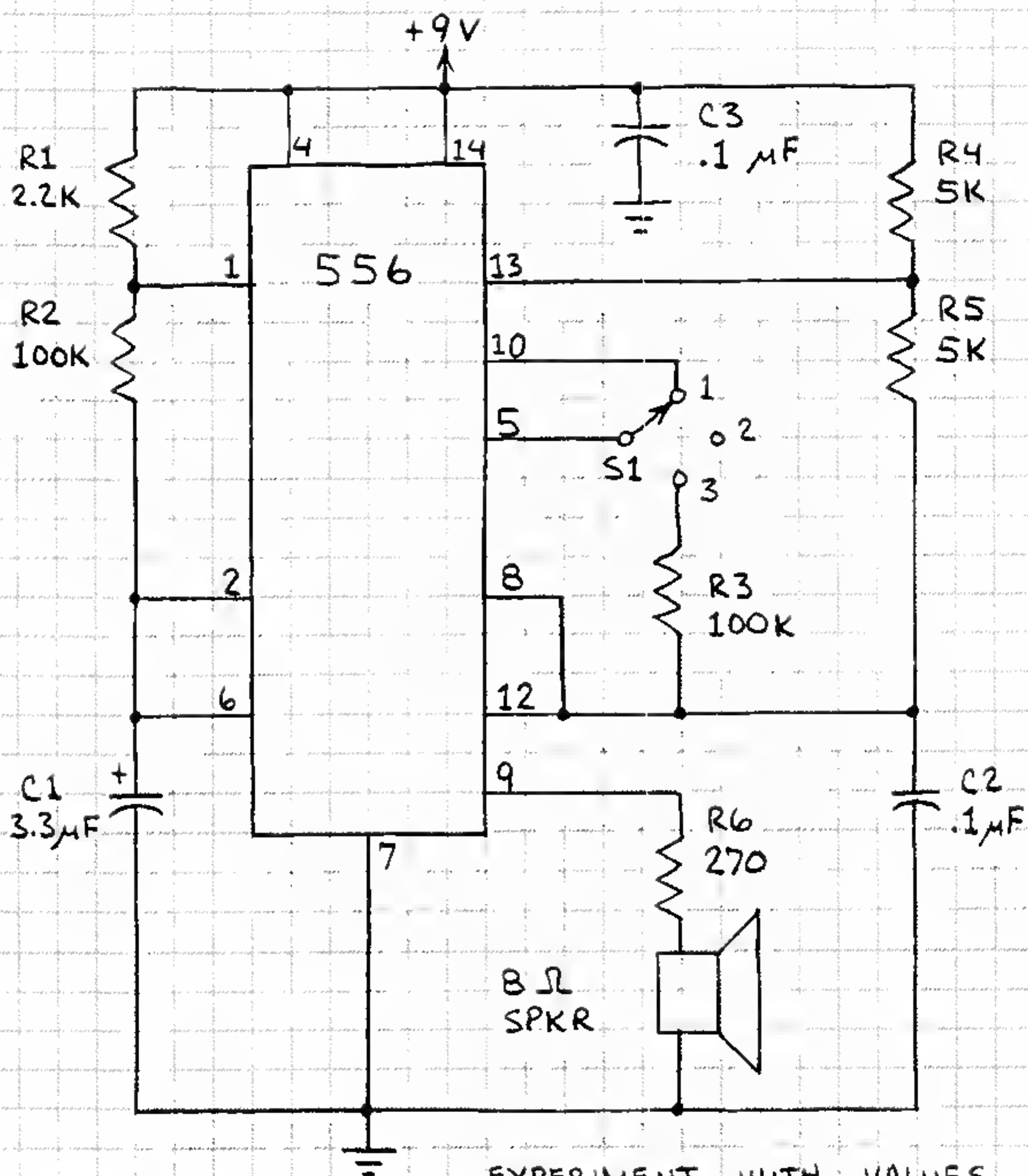


FREQUENCY FALLS AS R3 REDUCED



THIS CIRCUIT PRODUCES SOUNDS RESEMBLING PLUCKED VIOLIN STRINGS TO DRUM AS R1 AND R3 ARE ADJUSTED. FREQUENCY OF STEPPED OUTPUT DECREASES IN PROGRESSIVELY SMALLER INCREMENTS AS R3 IS REDUCED IN VALUE. GRAPH SHOWN HERE IS TYPICAL FOR VALUES SHOWN. OK TO CHANGE C1, C2 AND R1.

3-STATE TONE GENERATOR



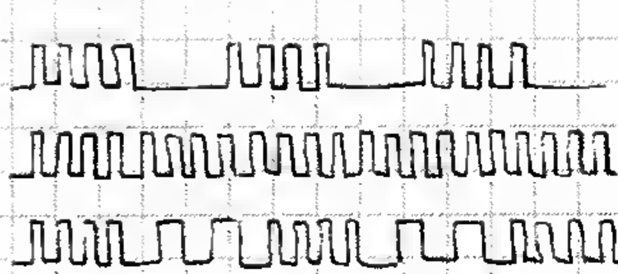
EXPERIMENT WITH VALUES OF R1, C1, R4 AND C2.

S1 (CENTER OFF):

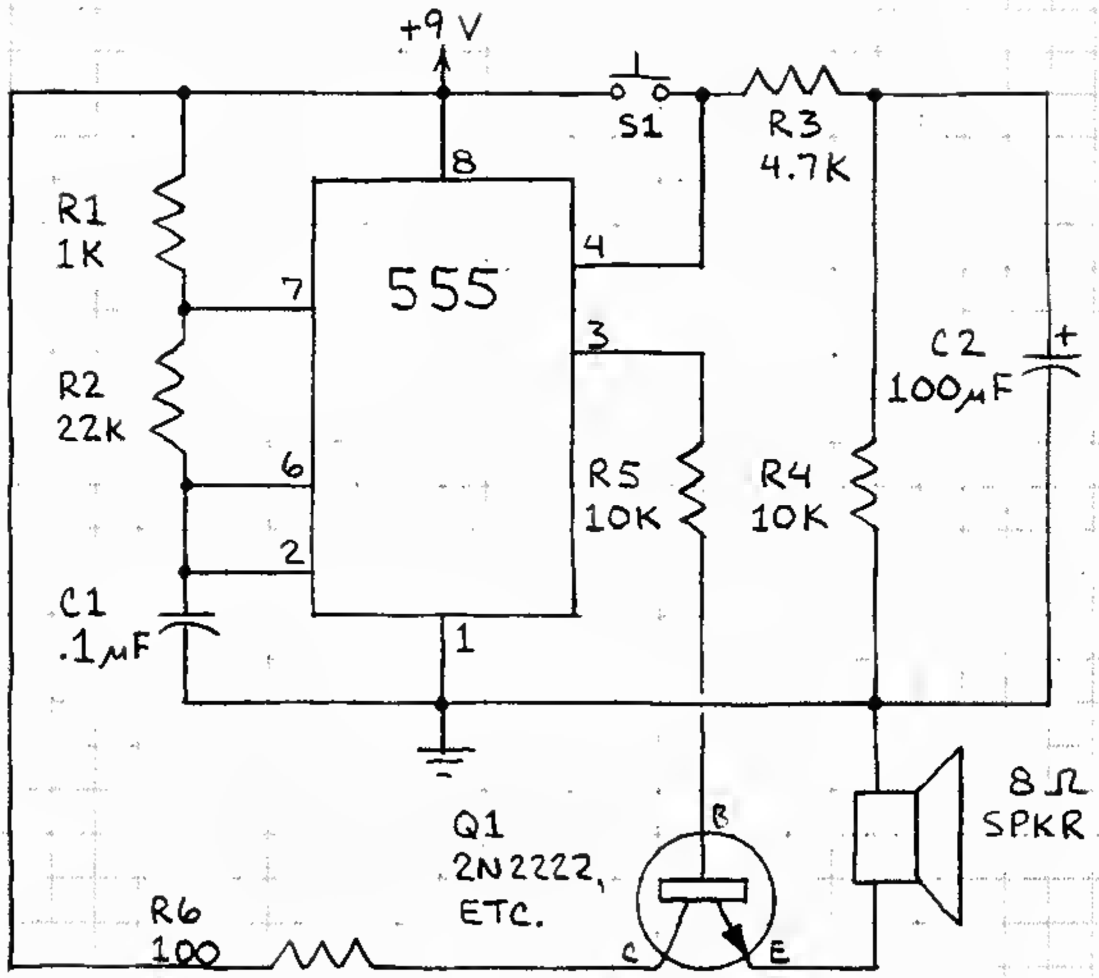
1 - TONE BURST

2 - STEADY TONE

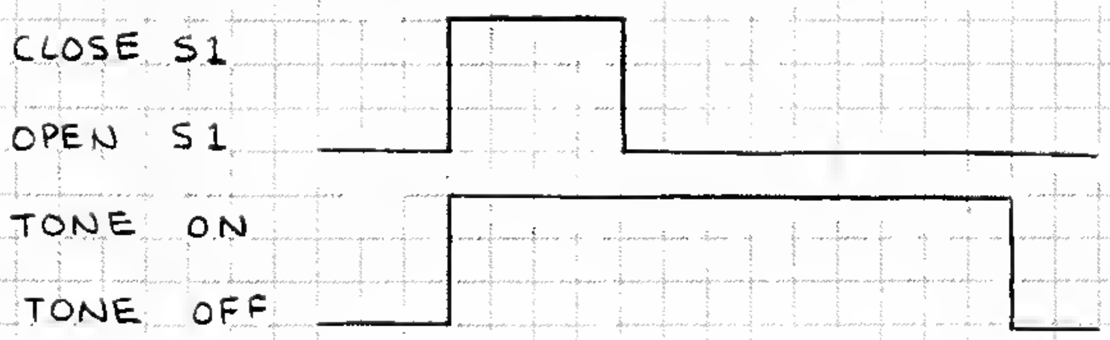
3 - TWO-TONE



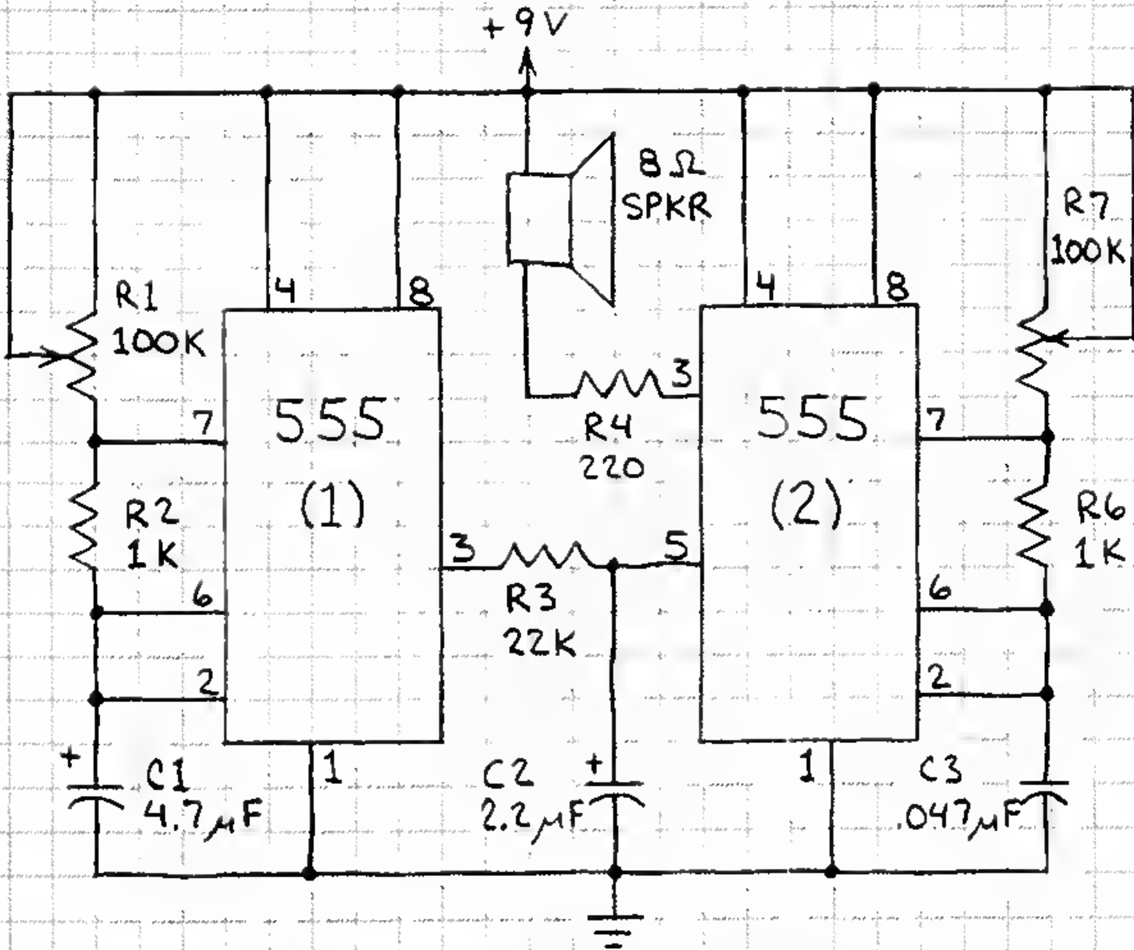
TONE BURST GENERATOR



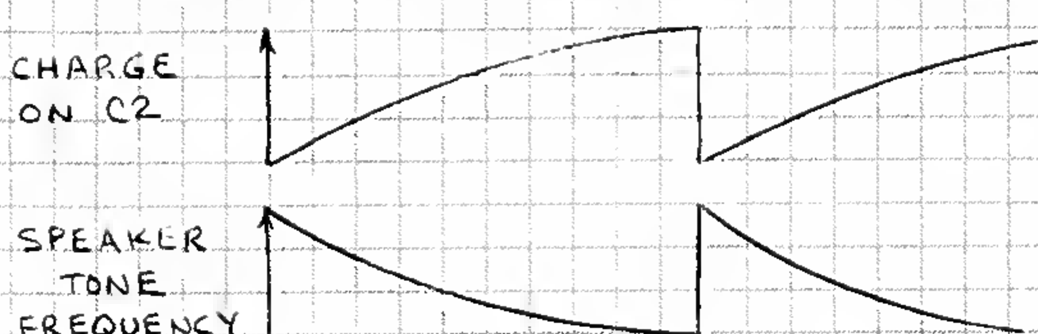
WHEN S1 IS CLOSED, THE SPEAKER EMITS A TONE WHOSE FREQUENCY IS DETERMINED BY R1 AND C1. WHEN S1 IS OPENED, THE TONE CONTINUES FOR SEVERAL SECONDS, THE TIME REQUIRED FOR C2 TO DISCHARGE THROUGH R4. INCREASE C2 TO INCREASE BURST DURATION.



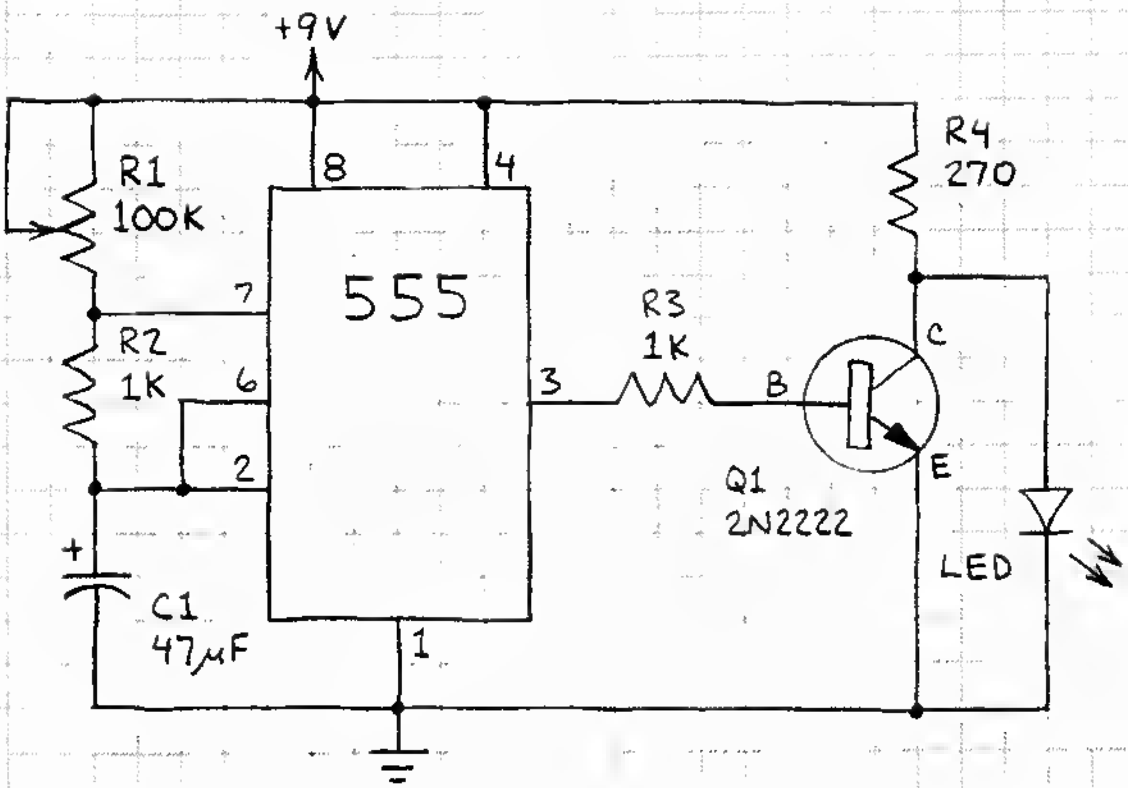
SOUND EFFECTS GENERATOR



THE FIRST 555 OSCILLATES AT A FREQUENCY DETERMINED BY R1 AND C1. ITS OUTPUT CHARGES C2 THROUGH R3. THE SECOND 555 OSCILLATES AT A FREQUENCY DETERMINED BY R7, C3 AND THE VOLTAGE AT PIN 5 (i.e. THE CHARGE ON C2). EXPERIMENT WITH THE SETTINGS OF R1 AND R7 AND THE VALUES OF R3 AND C2 TO OBTAIN WARBLE EFFECTS.



LED FLASHER



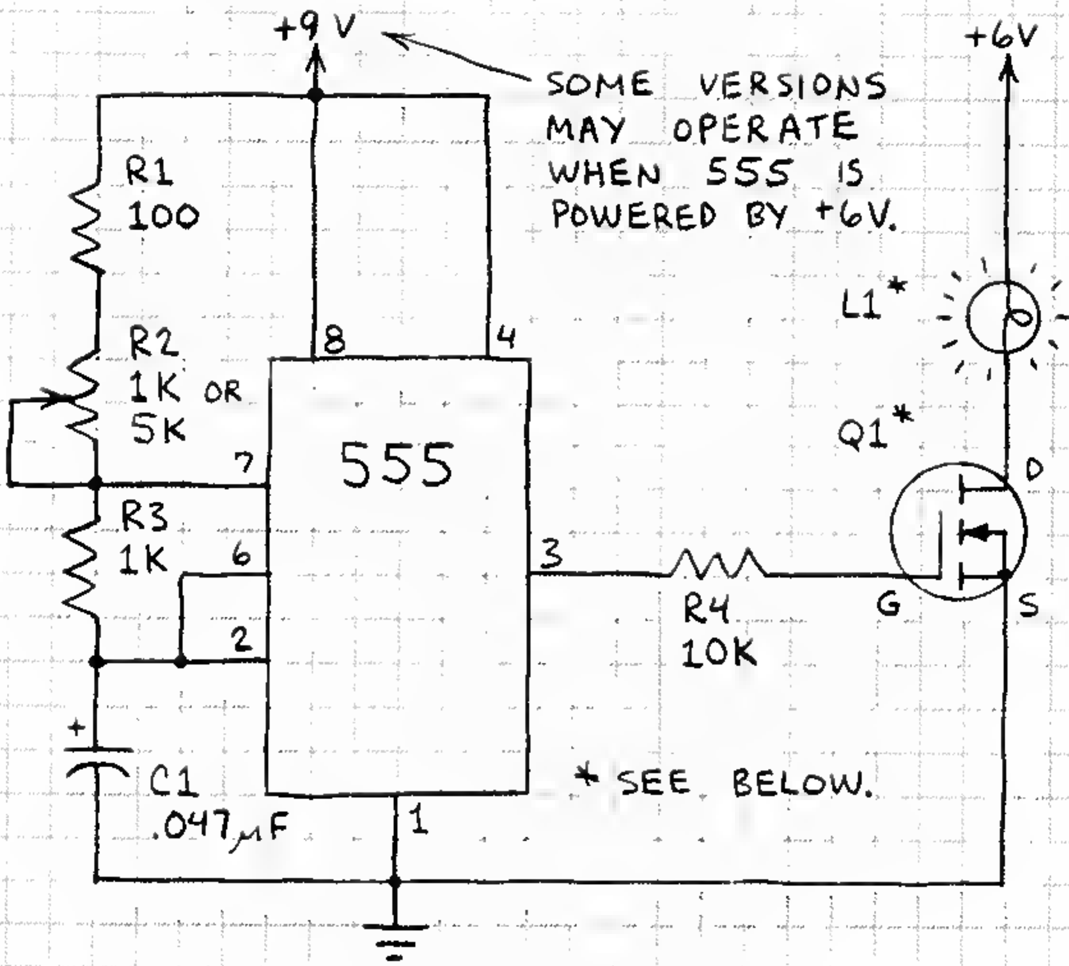
THIS CIRCUIT WILL DRIVE BOTH VISIBLE LIGHT AND INFRARED-EMITTING DIODES. USE RED, GREEN OR YELLOW LED TO MAKE A VISIBLE LIGHT FLASHER. USE NEAR-INFRARED EMITTER TO MAKE POWERFUL TRANSMITTER. CONNECT SOLAR CELL, PHOTODIODE OR PHOTOTRANSISTOR TO AMPLIFIER TO RECEIVE SIGNAL.

R1	RATE (Hz)
100 K	.2
47 K	.6
22 K	1.1
10 K	2.1
4.7 K	3.6
2.2 K	6.1
1.0 K	8.3

CONNECT PIEZO BUZZER ACROSS LED FOR LIGHT/SOUND DARKROOM TIMER.

REDUCE C1 FOR FASTER PULSE RATES, ESPECIALLY WHEN INFRARED EMITTER IS USED. SEE "GETTING STARTED IN ELECTRONICS" (RADIO SHACK, pp. 66-69).

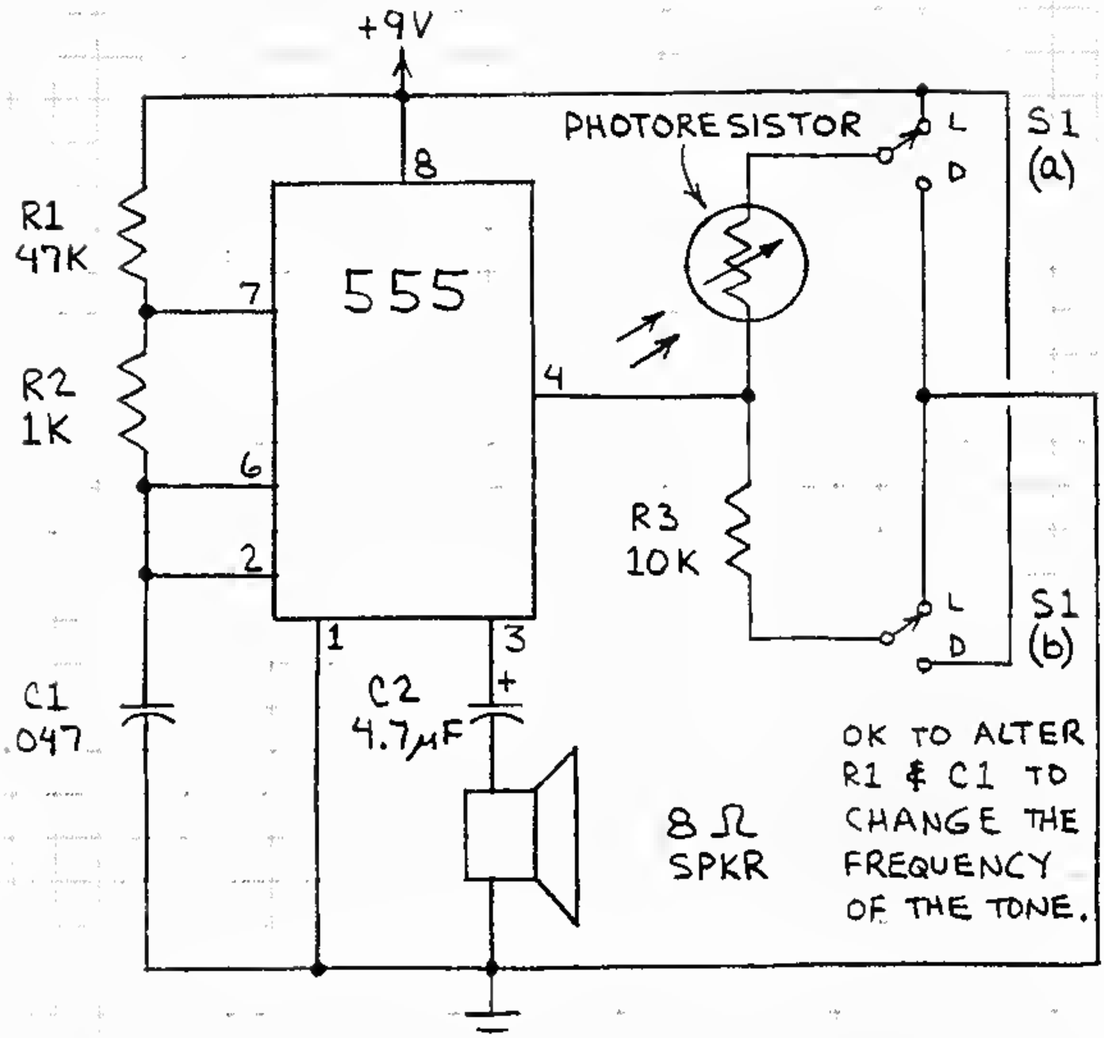
POWER FET LAMP DIMMER



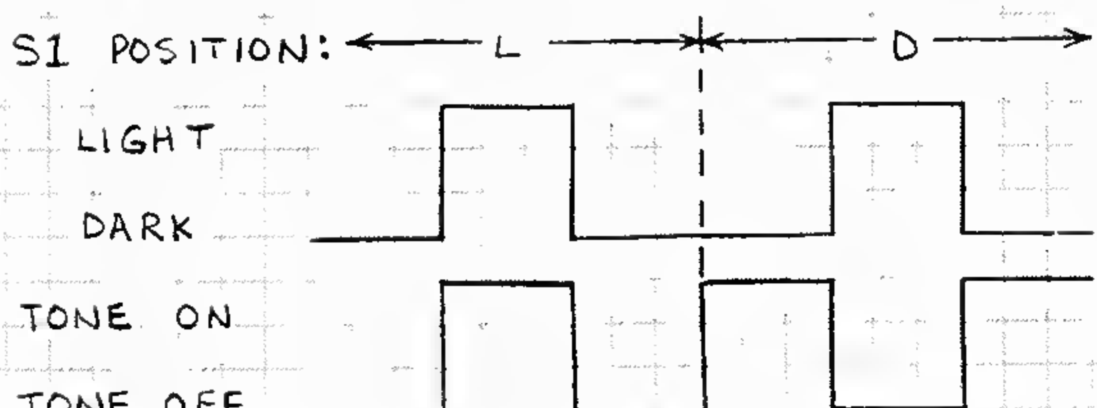
THIS CIRCUIT IS A LINEAR LAMP DIMMER. IN OPERATION, THE 555 SWITCHES Q1 ON AND OFF AT A RATE DETERMINED BY R1 + R2 AND C1. WHEN Q1 IS ON, L1 IS ALSO ON. THE SWITCHING RATE IS SO FAST L1 APPEARS TO GLOW CONTINUOUSLY. INCREASING THE SWITCHING RATE INCREASES THE APPARENT BRIGHTNESS OF L1.

Q1 MUST BE PROPERLY RATED. FOR EXAMPLE, A PR13 6-VOLT FLASHLIGHT LAMP CONSUMES 0.5 AMPERE OR 3 WATTS. THEREFORE USE AN IRF511 OR SIMILAR POWER FET. ATTACH A TO-220 HEATSINK TO DISSIPATE EXCESS HEAT.

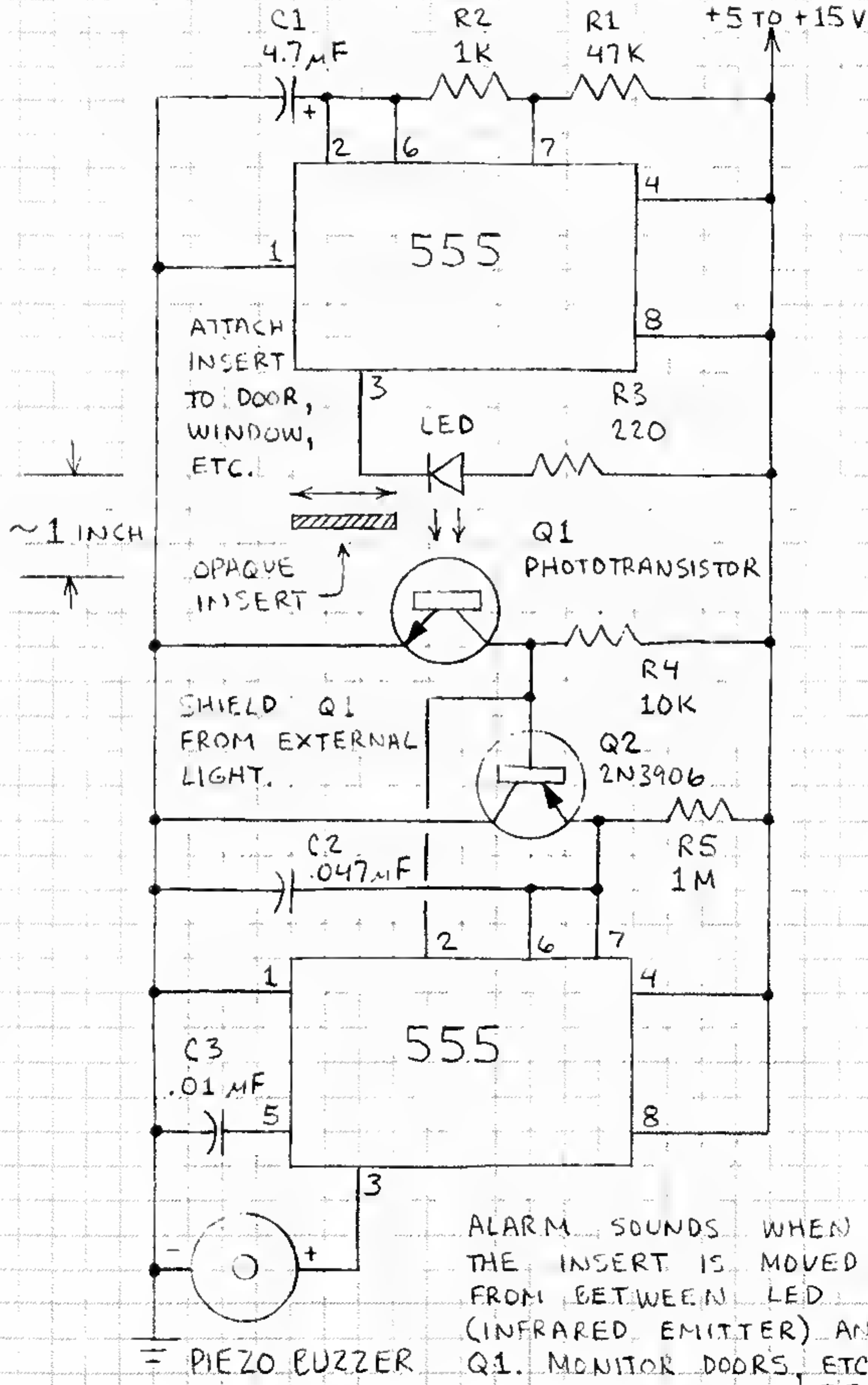
LIGHT / DARK DETECTOR



WHEN S1 IS IN POSITION "L" THE SPEAKER EMITS A TONE WHEN LIGHT STRIKES THE PHOTORESISTOR. WHEN S1 IS IN POSITION "D" THE SPEAKER EMITS A TONE WHEN THE PHOTORESISTOR IS NOT ILLUMINATED.

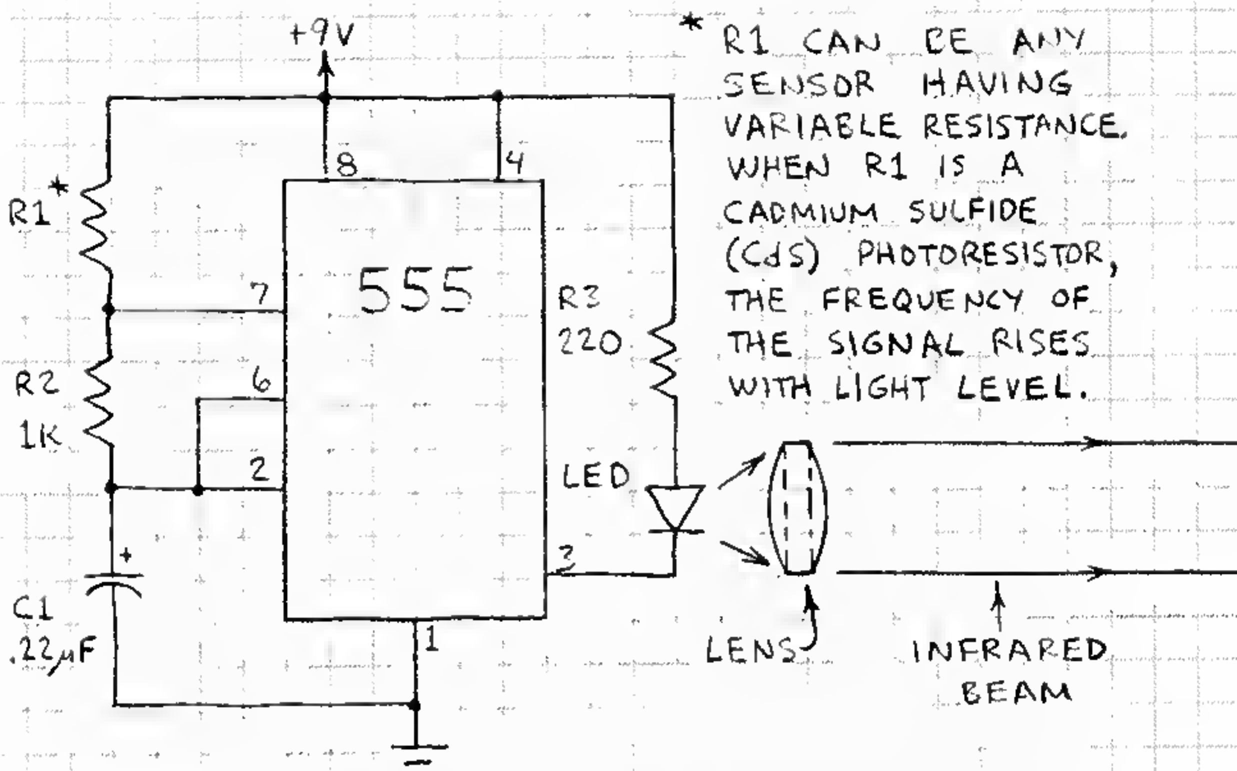


INFRARED SECURITY ALARM

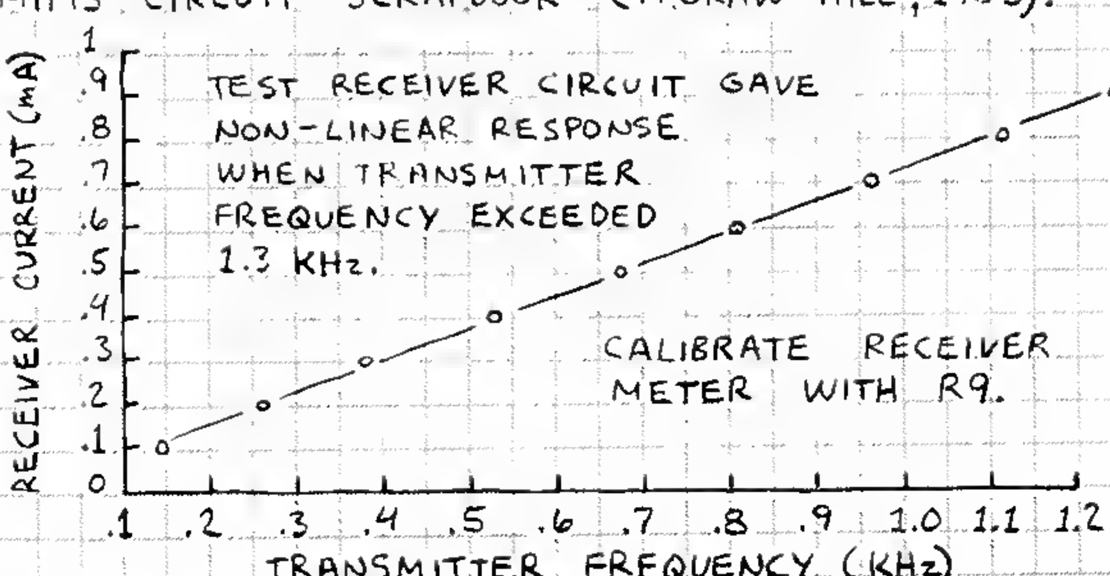


ALARM SOUNDS WHEN THE INSERT IS MOVED FROM BETWEEN LED (INFRARED EMITTER) AND Q1. MONITOR DOORS, ETC.

ANALOG LIGHTWAVE TRANSMITTER

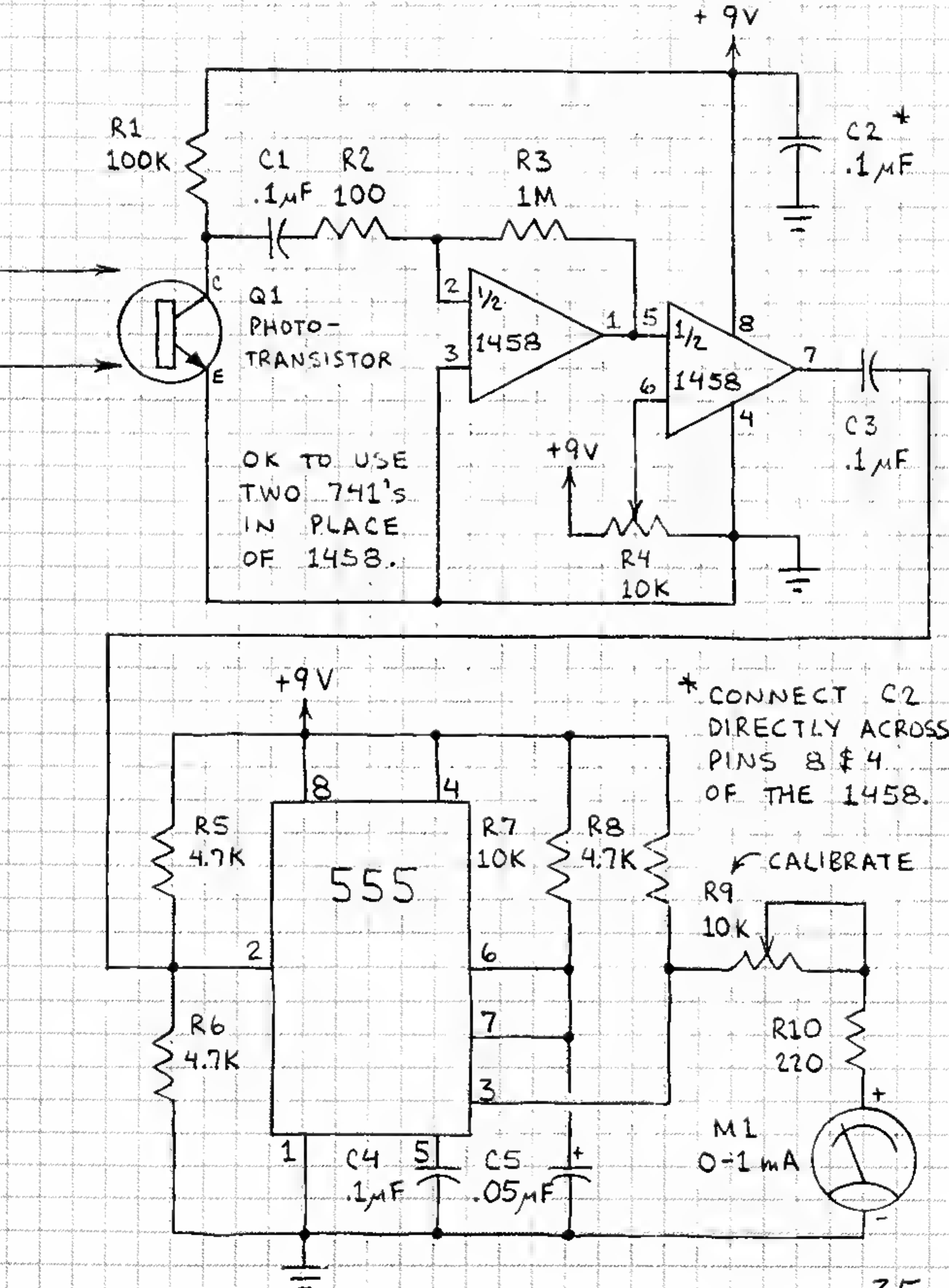


THIS CIRCUIT PULSES AN INFRARED-EMITTING DIODE AT A FREQUENCY DETERMINED BY R1 AND C1. THE RECEIVER ON THE FACING PAGE RECEIVES AND AMPLIFIES THE INFRARED SIGNAL. IT THEN CONVERTS THE SIGNAL'S FREQUENCY INTO A CURRENT WHICH IS DISPLAYED ON A 0-1 mA METER. USE LENSES TO INCREASE RANGE. FOR FULL DETAILS, SEE "THE FORREST MIMS CIRCUIT SCRAPBOOK" (McGRAW-HILL, 1983).

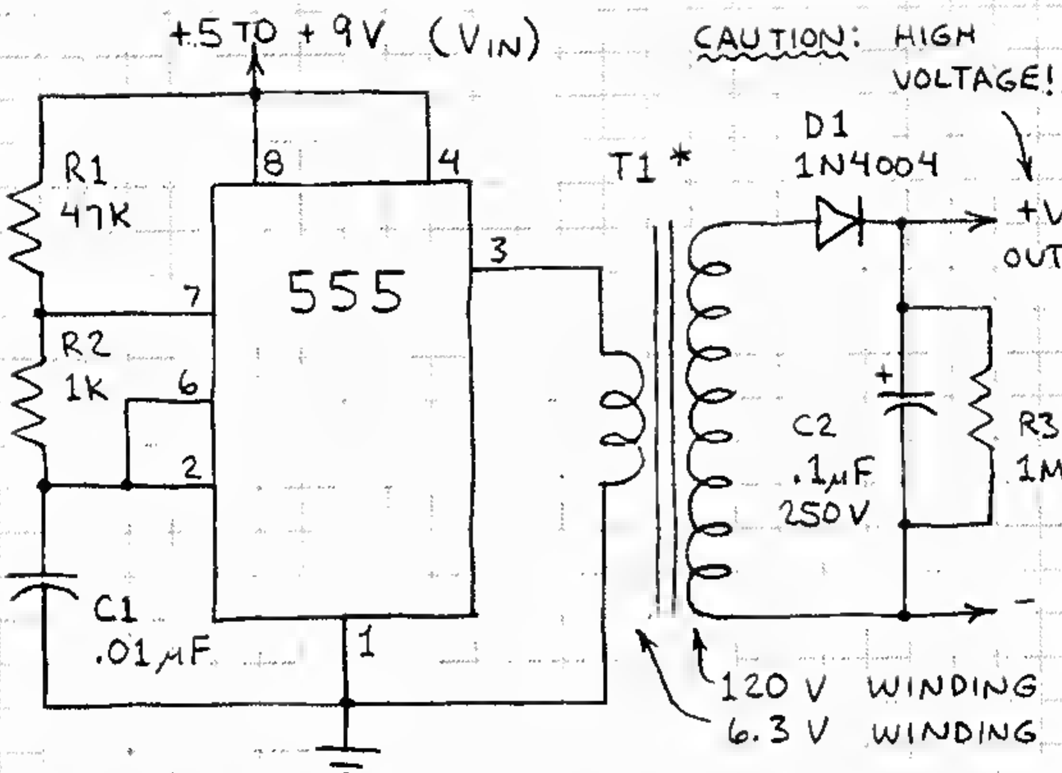


ANALOG LIGHTWAVE RECEIVER

THIS CIRCUIT RECEIVES PFM SIGNALS FROM THE TRANSMITTER ON FACING PAGE.

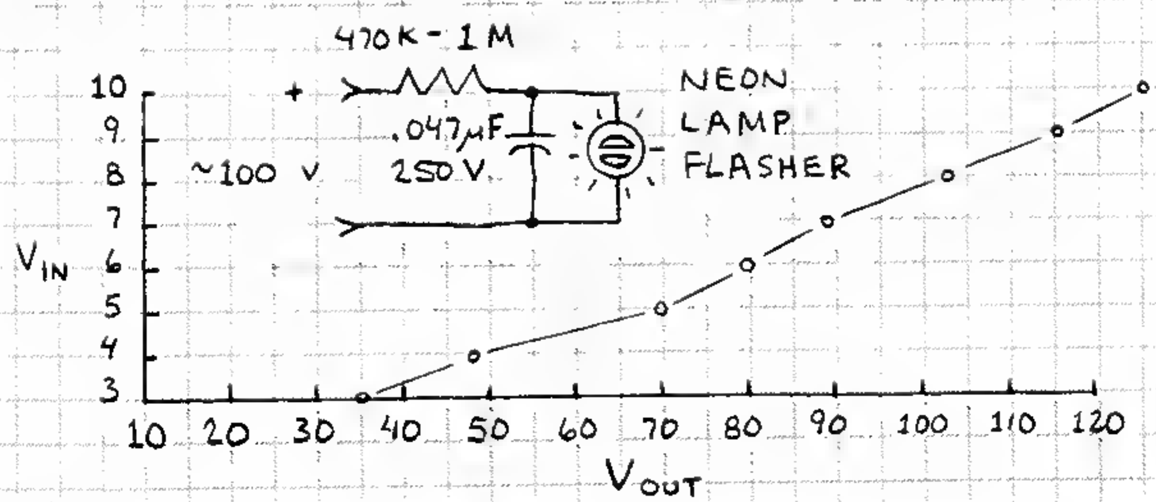


DC - DC CONVERTER



*T1: MINIATURE 6.3V: 120V POWER TRANSFORMER. (OK TO USE 6.3 V CENTER TAP OF 12.6V: 120V UNIT.)

THIS CIRCUIT APPLIES A PULSATING CURRENT TO A TRANSFORMER WINDING. THE INPUT VOLTAGE IS THEN BOOSTED BY THE TRANSFORMER'S SECOND WINDING. USE TO POWER NEON LAMPS, PLASMA DISPLAYS, ETC. CAUTION: DO NOT TOUCH OUTPUT LEADS! (R3 BLEEDS CHARGE FROM C2 WHEN V_{IN} IS REMOVED.)



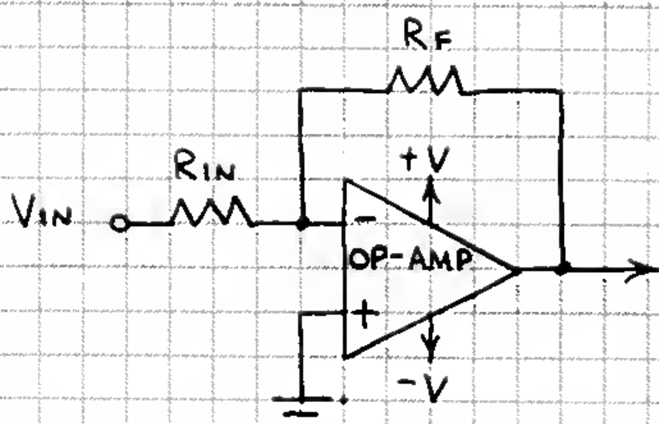
II. OP AMP PROJECTS

OVERVIEW

OP AMPS HAVE TWO INPUTS, INVERTING (−) AND NON-INVERTING (+), AND ONE OUTPUT. THE POLARITY OF A SIGNAL APPLIED TO THE INVERTING INPUT IS REVERSED AT THE OUTPUT. A SIGNAL APPLIED TO THE NON-INVERTING INPUT RETAINS ITS POLARITY AT THE OUTPUT.

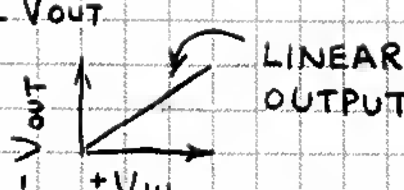
THE GAIN (DEGREE OF AMPLIFICATION) OF AN OP-AMP IS DETERMINED BY A FEEDBACK RESISTOR THAT FEEDS SOME OF THE AMPLIFIED SIGNAL FROM THE OUTPUT TO THE INVERTING INPUT. THIS REDUCES THE AMPLITUDE OF THE OUTPUT SIGNAL, HENCE THE GAIN. THE SMALLER THE RESISTOR, THE LOWER THE GAIN.

HERE IS A BASIC INVERTING AMPLIFIER MADE WITH AN OP-AMP:



GAIN = R_F / R_{IN}

$V_{OUT} = -V_{IN} (R_F / R_{IN})$

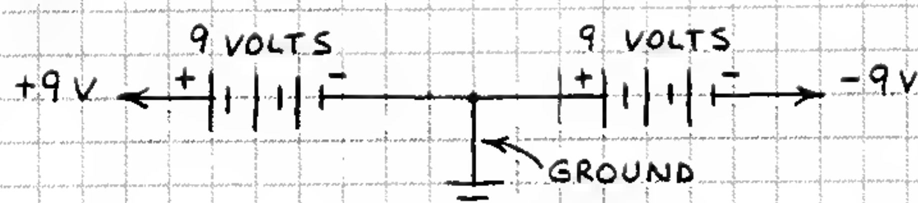


THE GAIN IS INDEPENDENT OF THE SUPPLY VOLTAGE. NOTE THAT THE UNUSED INPUT IS GROUNDED. THEREFORE THE OP AMP AMPLIFIES THE DIFFERENCE BETWEEN THE INPUT (V_{IN}) AND GROUND (0 VOLTS). THE OP-AMP IS THEN A DIFFERENTIAL AMPLIFIER.

THE FEEDBACK RESISTOR (R_F) AND AN OP-AMP FORM A CLOSED FEEDBACK LOOP. WHEN R_F IS OMITTED, THE OP-AMP IS SAID TO BE IN ITS OPEN LOOP MODE. THE OP-AMP THEN EXHIBITS MAXIMUM GAIN, BUT ITS OUTPUT THEN SWINGS FROM FULL ON TO FULL OFF OR VICE VERSA FOR VERY SMALL CHANGES IN INPUT VOLTAGE. THEREFORE THE OPEN LOOP MODE IS NOT PRACTICAL FOR LINEAR AMPLIFICATION. INSTEAD THIS MODE IS USED TO INDICATE WHEN THE VOLTAGE AT ONE INPUT DIFFERS FROM THAT AT THE OTHER. IN THIS MODE THE OP-AMP IS CALLED A COMPARATOR SINCE IT COMPARES ONE INPUT VOLTAGE WITH THE OTHER.

POWERING OP-AMPS

MOST OP-AMPS AND OP-AMP CIRCUITS REQUIRE A DUAL POLARITY POWER SUPPLY. HERE IS A SIMPLE DUAL POLARITY SUPPLY MADE FROM TWO 9-VOLT BATTERIES:



<u>IMPORTANT</u>: THE LEADS FROM THE SUPPLY TO THE OP-AMP SHOULD BE SHORT AND DIRECT. IF THEY EXCEED ABOUT 6 INCHES, THE OP-AMP'S SUPPLY PINS <u>MUST</u> BE BYPASSED BY CONNECTING A 0.1 μF CAPACITOR BETWEEN EACH POWER SUPPLY PIN AND GROUND. OTHERWISE THE OP-AMP MAY OSCILLATE OR FAIL TO OPERATE PROPERLY. ALWAYS USE FRESH BATTERIES. BOTH MUST SUPPLY THE SAME VOLTAGE. BE SURE THE BATTERY CLIPS ARE CLEAN AND TIGHT. <u>NEVER</u> APPLY AN INPUT SIGNAL WHEN THE POWER SUPPLY IS SWITCHED OFF.

OP-AMP SPECIFICATIONS

OP-AMPS ARE CHARACTERIZED BY DOZENS OF SPECIFICATIONS, SOME OF WHICH ARE GIVEN ON THE FOLLOWING PAGES. THOSE WHOSE MEANING IS NOT OBVIOUS ARE:

INPUT OFFSET VOLTAGE - EVEN WITH NO INPUT VOLTAGE AN OP-AMP GIVES A VERY SMALL OUTPUT VOLTAGE. THE OFFSET VOLTAGE IS THAT WHICH, WHEN APPLIED TO ONE INPUT, CAUSES THE OUTPUT TO BE AT 0 VOLTS.

COMMON MODE REJECTION RATIO - THIS IS A MEASURE OF THE ABILITY OF AN OP-AMP TO REJECT A SIGNAL SIMULTANEOUSLY APPLIED TO BOTH INPUTS.

BANDWIDTH - THE FREQUENCY RANGE OVER WHICH AN OP-AMP WILL FUNCTION. THE FREQUENCY AT WHICH THE GAIN FALLS TO 1 IS THE UNITY GAIN FREQUENCY.

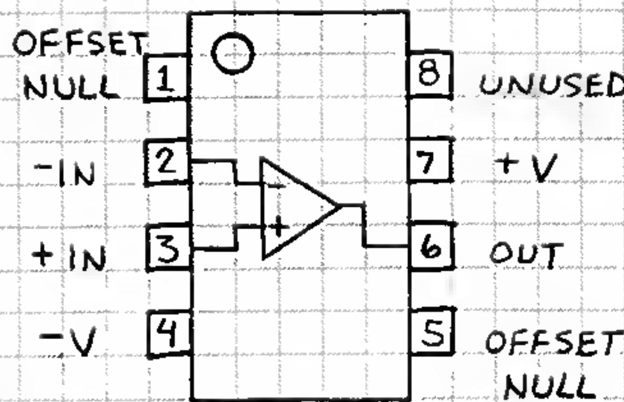
SLEW RATE - THE RATE OF CHANGE IN THE OUTPUT OF AN OP-AMP IN VOLTS PER MICROSECOND WHEN THE GAIN IS 1.

CIRCUIT ASSEMBLY TIPS

YOU CAN USUALLY SUBSTITUTE DIFFERENT OP-AMPS IN A CIRCUIT. FOR EXAMPLE, USE A 1458 DUAL OP-AMP IN A CIRCUIT THAT REQUIRES TWO 741 OP-AMPS. BE SURE TO KEEP TRACK OF PIN DIFFERENCES. FOR VERY HIGH INPUT RESISTANCE AND LOW OPERATING CURRENT, USE CMOS OP-AMPS. USE A HIGH-IMPEDANCE VOLTMETER TO MONITOR THE OUTPUT OF AN OP-AMP THAT IS AMPLIFYING A d.c. VOLTAGE. IF A CIRCUIT FAILS TO WORK, REMOVE INPUT SIGNAL <u>FIRST</u>. THEN DISCONNECT POWER AND CHECK THE WIRING. USE FRESH BATTERIES.

741 OP-AMP

THE 741 IS A HIGHLY POPULAR GENERAL PURPOSE OP-AMP. IT IS SIMPLE TO USE, RELIABLE, AND INEXPENSIVE. IT IS USUALLY OK TO SUBSTITUTE NEWER OPAMPS FOR THE 741.



MAXIMUM RATINGS

SUPPLY VOLTAGE	±18 V
POWER DISSIPATION	500 mW
DIFFERENTIAL INPUT VOLTAGE	±30 V
INPUT VOLTAGE (NOTE 1)	±15 V
OUTPUT SHORT CIRCUIT TIME	INDEFINITE
OPERATING TEMPERATURE	0°C TO 70°C

NOTE 1: INPUT VOLTAGE SHOULD NOT EXCEED SUPPLY VOLTAGE WHEN SUPPLY VOLTAGE IS LESS THAN ±15 VOLTS.

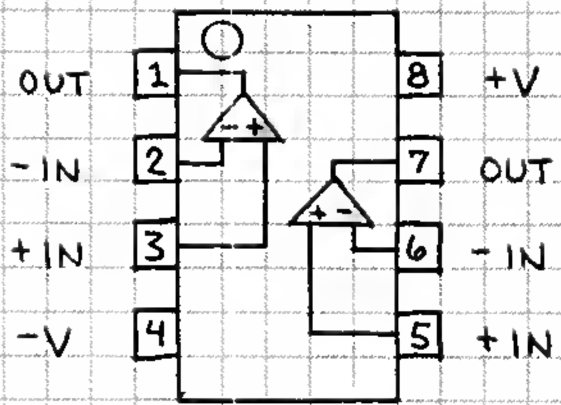
CHARACTERISTICS (NOTE 2)

INPUT OFFSET VOLTAGE	2 TO 6 mV
INPUT RESISTANCE	.3 TO 2 MΩ
VOLTAGE GAIN	20,000 TO 200,000
COMMON-MODE REJECTION RATIO	70 TO 90 dB
BANDWIDTH	.5 TO 1.5 MHz
SLEW RATE	.5 V / μSEC
SUPPLY CURRENT	1.7 TO 2.8 mA
POWER CONSUMPTION	50 TO 85 mW

NOTE 2: VALUES SHOWN ARE TYPICAL OR MINIMUM TO TYPICAL.

1458 DUAL OP-AMP

THE 1458 INCLUDES TWO INDEPENDENT, GENERAL PURPOSE OP-AMPS IN A SINGLE PACKAGE. THE AMPLIFIERS SHARE COMMON POWER SUPPLY PINS. USE TO REPLACE TWO 741 OP-AMPS.



MAXIMUM RATINGS

SUPPLY VOLTAGE	±18 V
POWER DISSIPATION	400 mW
DIFFERENTIAL INPUT VOLTAGE	±30 V
INPUT VOLTAGE (NOTE 1)	±15 V
OUTPUT SHORT CIRCUIT TIME	INDEFINITE
OPERATING TEMPERATURE	0°C TO 70°C

NOTE 1: INPUT VOLTAGE SHOULD NOT EXCEED SUPPLY VOLTAGE WHEN SUPPLY VOLTAGE IS LESS THAN ±15 V.

CHARACTERISTICS (NOTE 2)

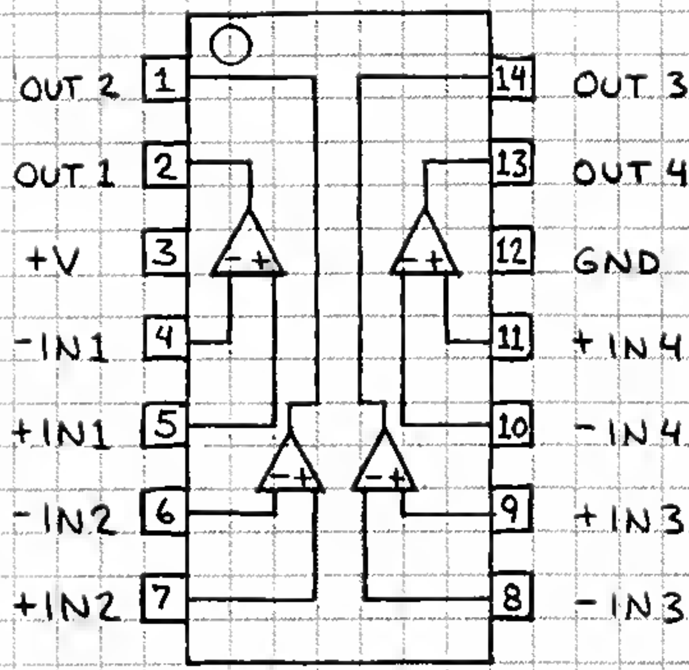
INPUT OFFSET VOLTAGE	1 TO 6 mV
INPUT RESISTANCE	.3 TO 1 MΩ
VOLTAGE GAIN	20,000 TO 160,000
COMMON-MODE REJECTION RATIO	70 TO 90 dB
SUPPLY CURRENT (NOTE 3)	3 TO 5.6 mA
POWER CONSUMPTION	85 mW

NOTE 2: VALUES SHOWN ARE TYPICAL OR MINIMUM TO TYPICAL.

NOTE 3: BOTH AMPLIFIERS.

339 QUAD COMPARATOR

THE 339 CONTAINS FOUR INDEPENDENT COMPARATORS, MAKING IT AN ECONOMICAL APPROACH TO COMPARATOR CIRCUITS. IT OPERATES FROM A SINGLE POLARITY POWER SUPPLY.



MAXIMUM RATINGS

SUPPLY VOLTAGE	+36V OR ±18V
POWER DISSIPATION	570 mW
DIFFERENTIAL INPUT VOLTAGE	36 V
INPUT VOLTAGE	-.3V TO +36V
OUTPUT SHORT CIRCUIT (NOTE 1)	CONTINUOUS
OPERATING TEMPERATURE	0°C TO 70°C

NOTE 1: OK TO SHORT OUTPUT TO GROUND. DO NOT SHORT OUTPUT TO +V SINCE CHIP WILL OVERHEAT.

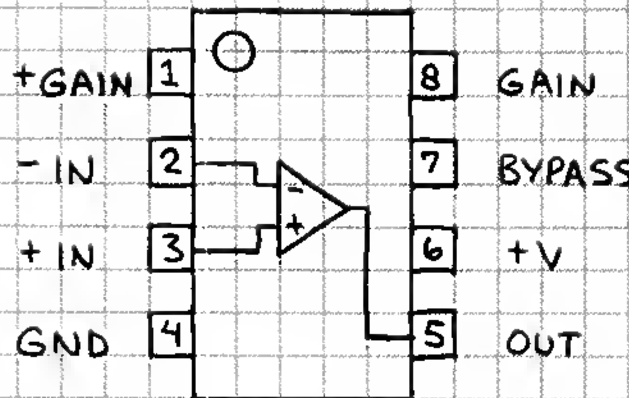
CHARACTERISTICS (NOTE 2)

INPUT OFFSET VOLTAGE	±3 TO ±20 mV
VOLTAGE GAIN	2,000 TO 30,000
SUPPLY CURRENT	.8 TO 2 mA
OUTPUT SINK CURRENT	6 TO 16 mA

NOTE 2: VALUES SHOWN ARE MINIMUM TO TYPICAL.

386 AUDIO AMPLIFIER

SIMPLE TO USE AUDIO AMPLIFIER WITH GAIN OF 20. OPERATES FROM SINGLE POLARITY SUPPLY. CONNECT 10 μF CAPACITOR BETWEEN PINS 1 AND 8 FOR GAIN OF 200.



MAXIMUM RATINGS

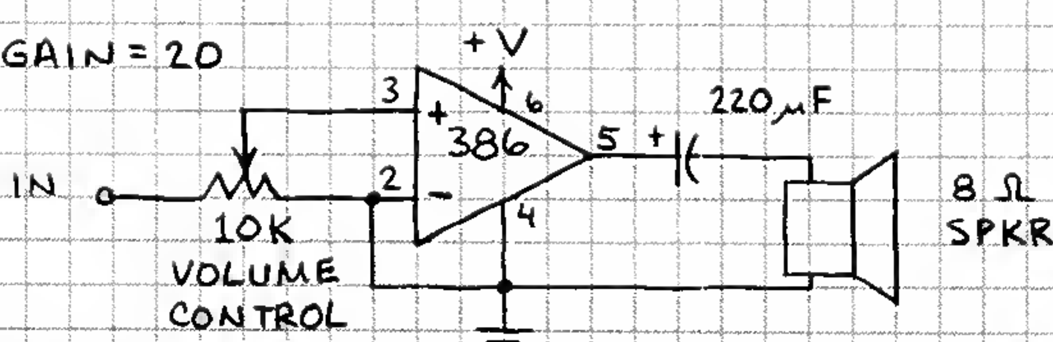
SUPPLY VOLTAGE	+15 V
POWER DISSIPATION	660 mW
INPUT VOLTAGE	±0.4 V
OPERATING TEMPERATURE	0°C TO 70°C

CHARACTERISTICS

SUPPLY VOLTAGE RANGE	+4 TO +12 V
STANDBY CURRENT	4 TO 8 mA
OUTPUT POWER	250 TO 325 mW
VOLTAGE GAIN	20 TO 200
BANDWIDTH	300 KHz
TOTAL HARMONIC DISTORTION	0.2 %
INPUT RESISTANCE	50K Ω

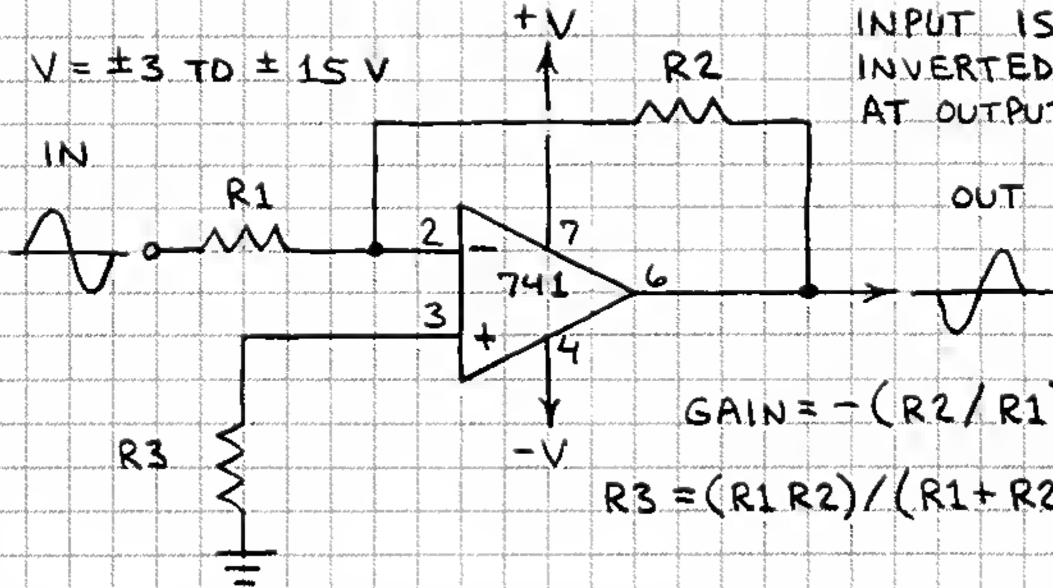
TYPICAL APPLICATION

GAIN = 20



BASIC INVERTING AMPLIFIER

V = ±3 TO ±15 V



INPUT IS INVERTED AT OUTPUT.

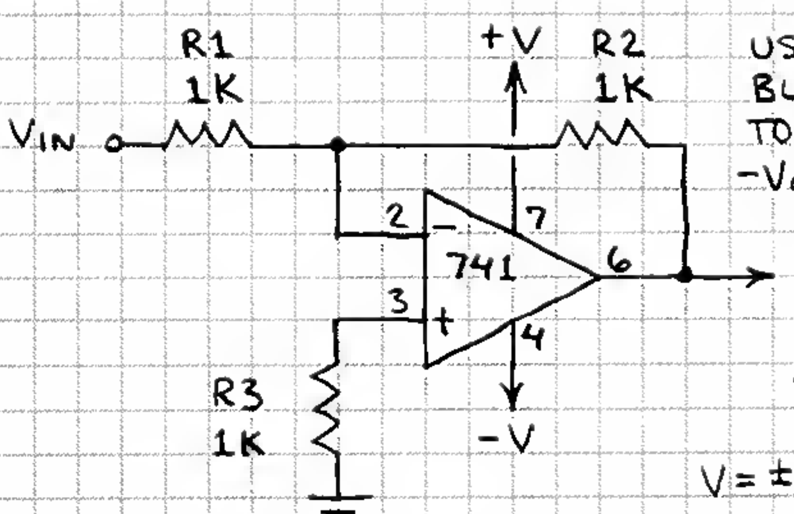
GAIN = −(R2/R1)

R3 = (R1 R2)/(R1 + R2)

EXAMPLE: IF R1 = 1000 OHMS AND R2 = 10,000 OHMS, THEN GAIN IS −(10,000/1000) OR −10.

THIS IS ONE OF THE MOST COMMON OP-AMP CIRCUITS. FOR A NON-INVERTED OUTPUT USE THE AMPLIFIER ON THE FACING PAGE. FOR SINGLE SUPPLY OP AMPS, CONNECT PIN 4 TO ⏚.

UNITY-GAIN INVERTER

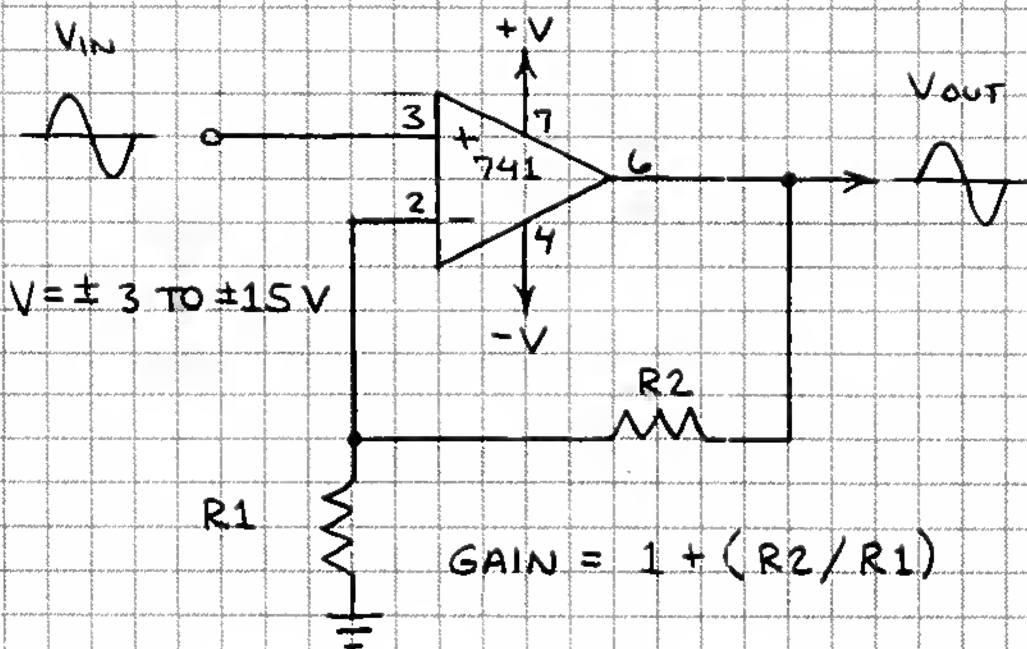


USE AS A BUFFER OR TO CONVERT $-V_{OUT}$ TO $+V_{OUT}$.

$V_{OUT} = -V_{IN}$

V = ±3 TO ±15 V

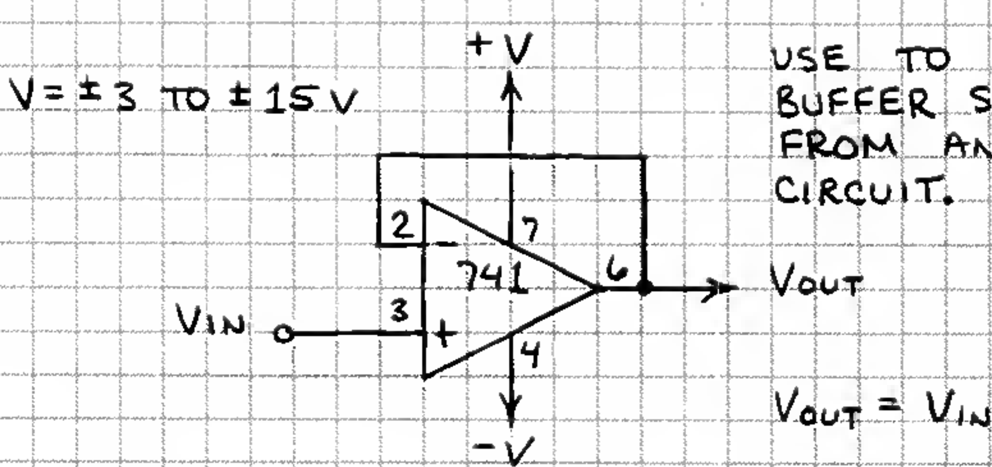
NON-INVERTING AMPLIFIER



EXAMPLE: IF R1 = 1,000 OHMS AND R2 = 10,000 OHMS, THEN GAIN IS 1 + (10,000 / 1,000) OR 11.

NOTE THAT VOUT IS AN AMPLIFIED BUT NOT INVERTED VERSION OF VIN.

UNITY-GAIN FOLLOWER



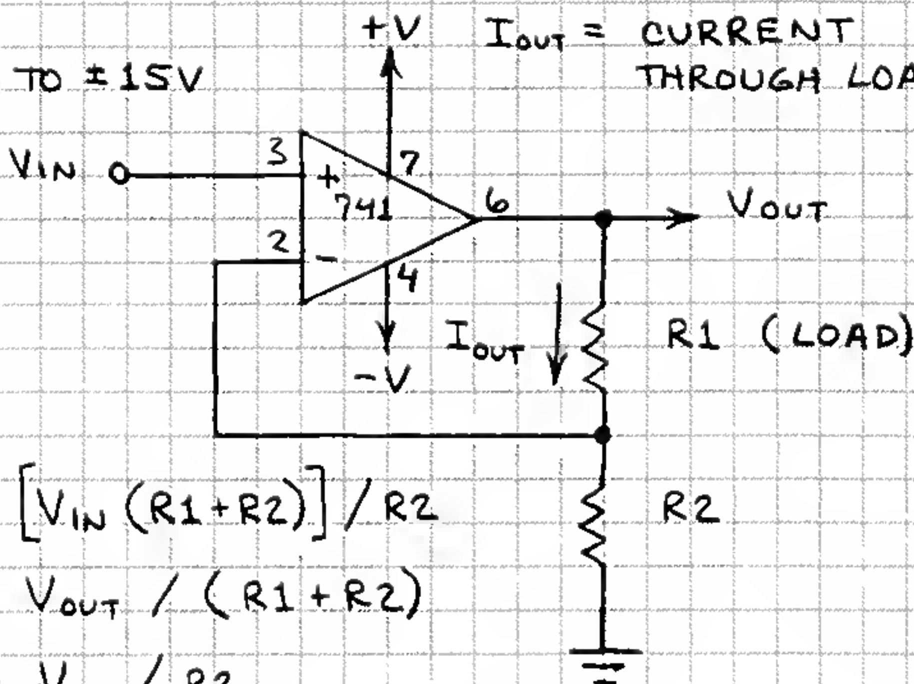
USE TO BUFFER SIGNAL FROM ANOTHER CIRCUIT.

$V_{OUT} = V_{IN}$

TRANSCONDUCTANCE AMPLIFIER

V= ±3 TO ±15V

I_{OUT} = CURRENT THROUGH LOAD.

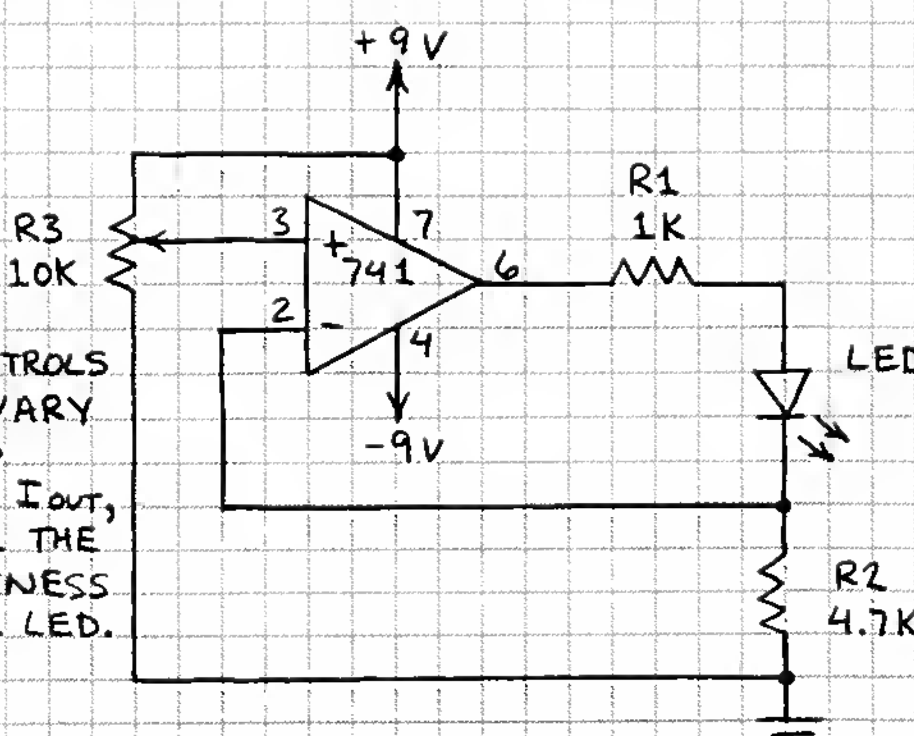


$V_{OUT} = [V_{IN}(R1+R2)]/R2$

$I_{OUT} = V_{OUT}/(R1+R2)$

$I_{OUT} = V_{IN}/R2$

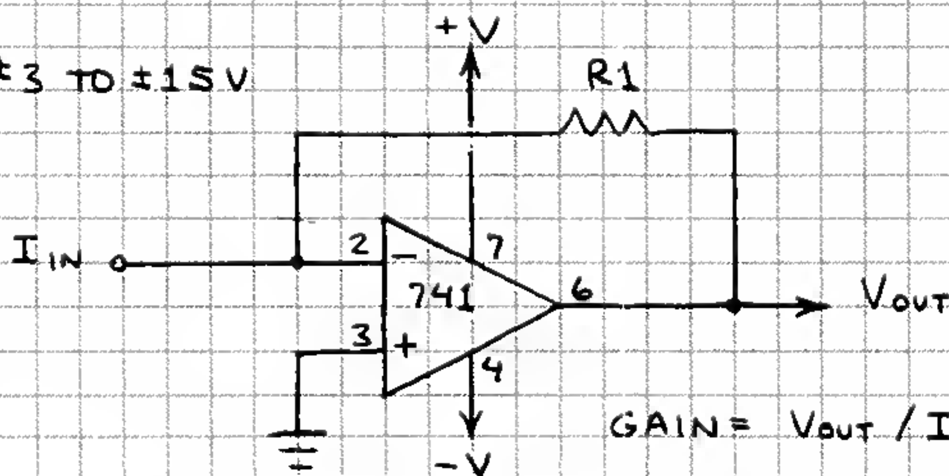
THIS CIRCUIT IS A VOLTAGE-TO-CURRENT CONVERTER. HERE'S HOW IT PERMITS AN INPUT VOLTAGE TO CONTROL THE BRIGHTNESS OF AN LED:



R3 CONTROLS V_{IN}. VARY R3 TO ALTER I_{OUT}, HENCE THE BRIGHTNESS OF THE LED.

TRANSIMPEDANCE AMPLIFIER

V = ±3 TO ±15 V

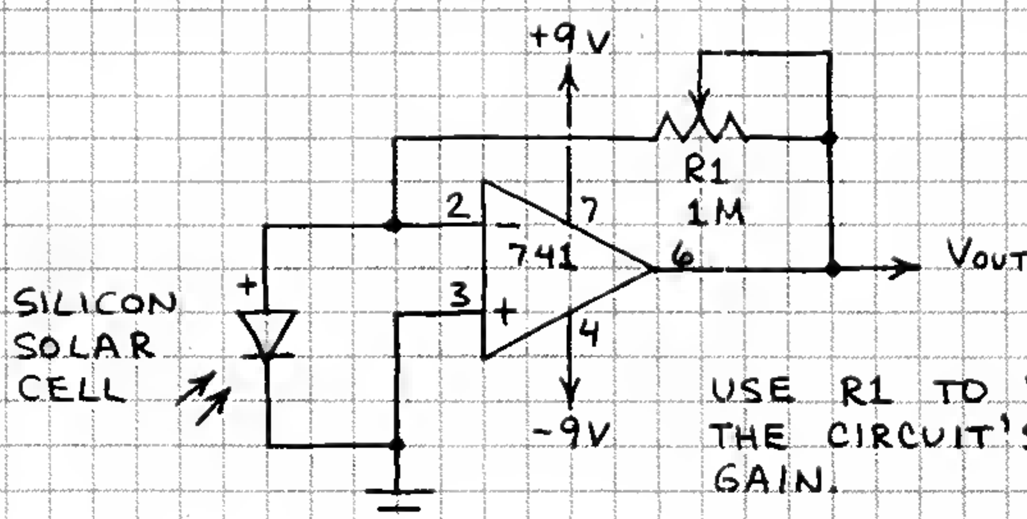


GAIN = V_{OUT} / I_{IN}

GAIN = −R1

EXAMPLE: IF R1 = 1,000 OHMS THEN GAIN = −1,000.

THIS CIRCUIT IS A CURRENT-TO-VOLTAGE CONVERTER. HERE'S HOW IT TRANSFORMS THE CURRENT GENERATED BY A SOLAR CELL INTO AN OUTPUT VOLTAGE:

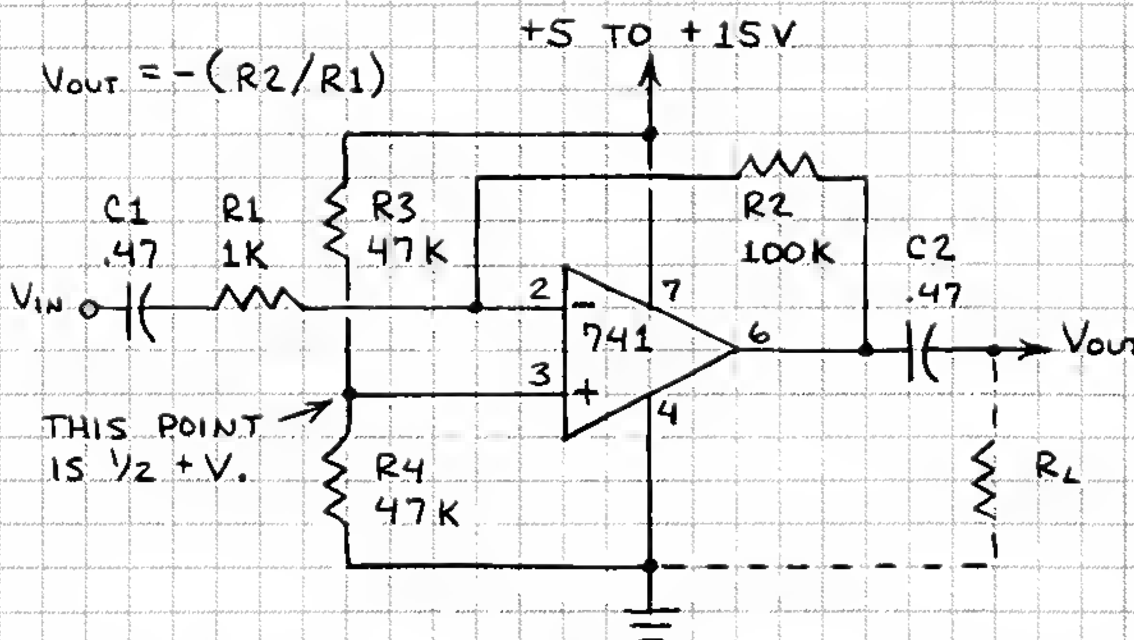


USE R1 TO VARY THE CIRCUIT'S GAIN.

THIS CIRCUIT CAN AMPLIFY THE SIGNAL FROM NON-CURRENT GENERATORS LIKE THERMISTORS AND PHOTORESISTORS. CONNECT ONE SIDE OF DEVICE TO +9V AND THE OTHER TO PIN 2. GROUND PIN 3. OK TO USE NEWER SINGLE SUPPLY OP AMP (CONNECT PIN 4 TO ⏚).

SINGLE-SUPPLY AMPLIFIER

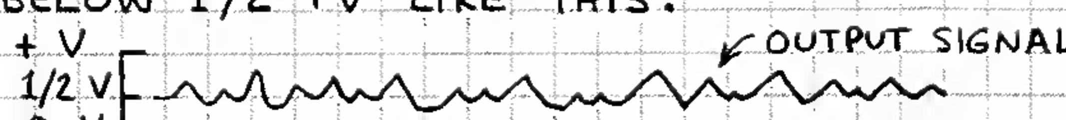
$V_{OUT} = -(R2/R1)$



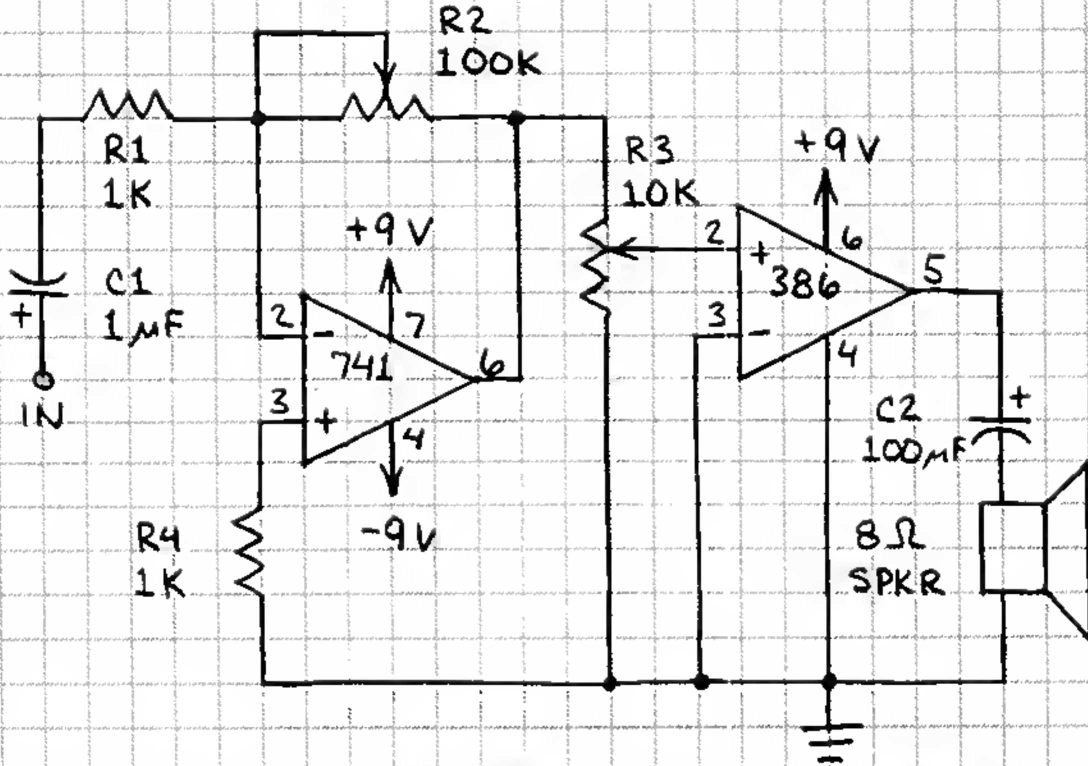
THIS IS AN INVERTING AMPLIFIER DESIGNED TO OPERATE FROM A SINGLE-POLARITY SUPPLY. WITH THE VALUES FOR R1 AND R2 GIVEN ABOVE, THE GAIN IS 100. CAPACITORS C1 AND C2 MUST BE USED. THEREFORE THIS CIRCUIT WILL AMPLIFY A FLUCTUATING AC SIGNAL BUT NOT A DC SIGNAL.

C1 SHOULD BE APPROXIMATELY $1/(2\pi f_{LOW} R1)$. (f_{LOW} IS THE LOW FREQUENCY CUTOFF OR 300 Hz FOR THE CIRCUIT ABOVE.) C2 SHOULD BE APPROXIMATELY $1/(2\pi f_{LOW} R_L)$. (R_L IS THE LOAD RESISTANCE.)

THE OUTPUT FROM A DUAL-SUPPLY OP-AMP CAN FLUCTUATE ABOVE AND BELOW GROUND (0 VOLTS). HERE THE DIVIDER FORMED BY R3 AND R4 SETS V_{OUT} AT 1/2 +V. THE OUTPUT THEN FLUCTUATES ABOVE AND BELOW 1/2 +V LIKE THIS:

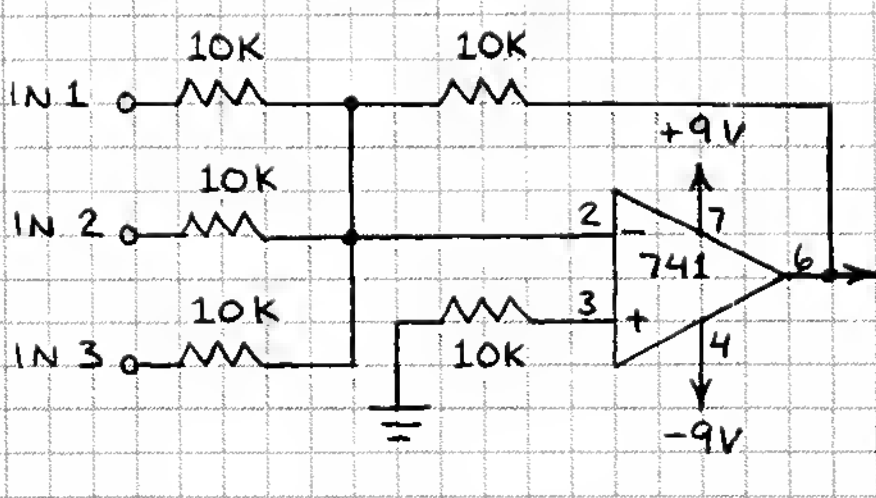


AUDIO AMPLIFIER



THE 741 IS A PREAMPLIFIER. R2 CONTROLS ITS GAIN. THE 386 IS A POWER AMPLIFIER. R3 CONTROLS THE VOLUME OF THE SPEAKER. OK TO USE FIXED 100K RESISTOR FOR R2. (REDUCE RESISTANCE OF R2 IF CIRCUIT OSCILLATES OR GIVES DISTORTED OUTPUT.) <u>IMPORTANT</u>: BYPASS THE POWER SUPPLY CONNECTIONS WITH 0.1 μF CAPACITORS.

AUDIO MIXER

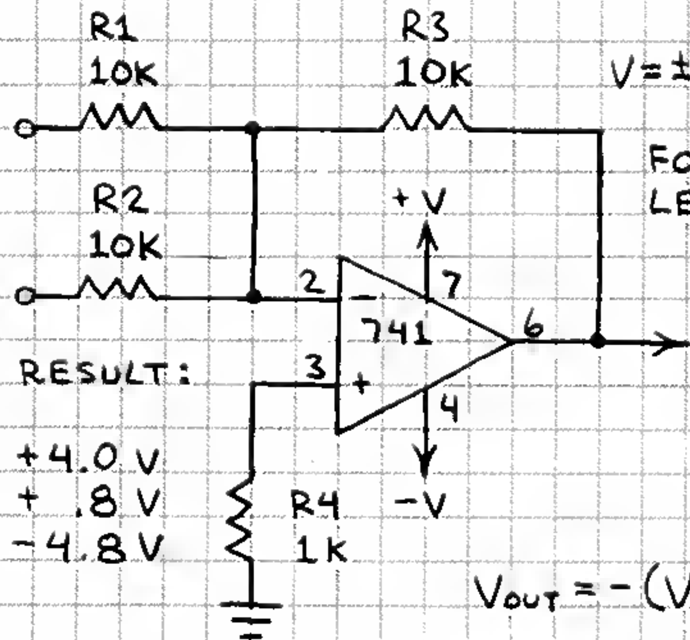


OUTPUT

OK TO USE WITH THE AMPLIFIER ABOVE.

USE WITH MULTIPLE MICROPHONES.

SUMMING AMPLIFIER



V = ±5 TO ±15 V

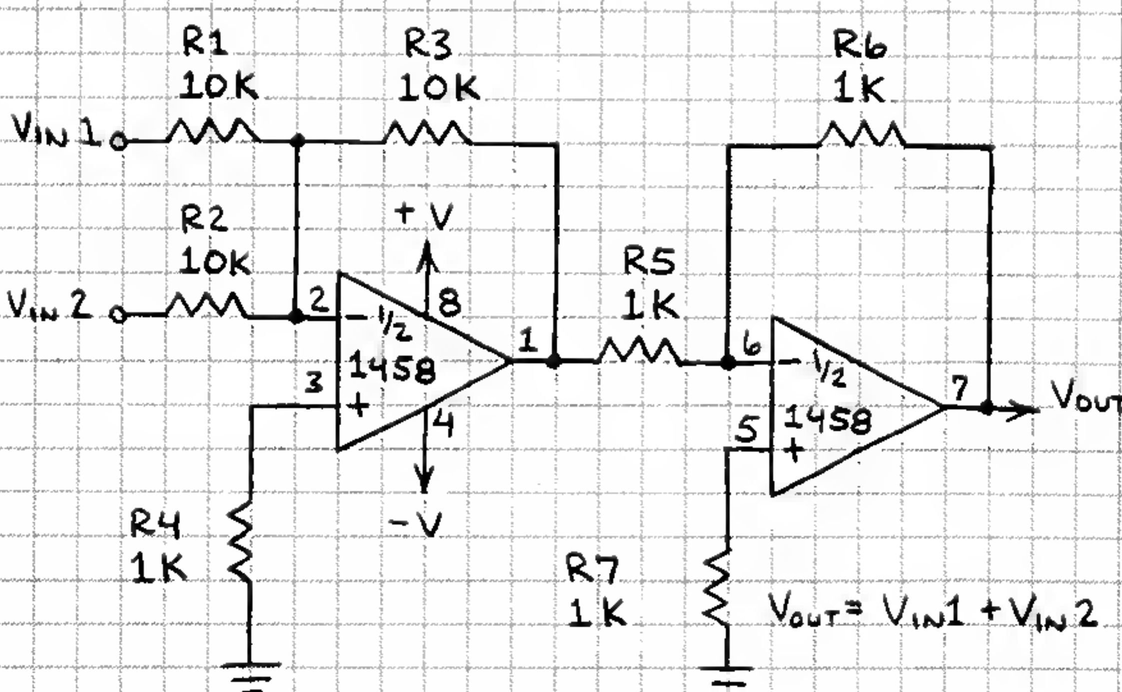
FOR TEST AT LEFT V = ±10V.

TEST RESULT:

$V_{IN}1 = +4.0$ V
$V_{IN}2 = +\ .8$ V
$V_{OUT} = -4.8$ V

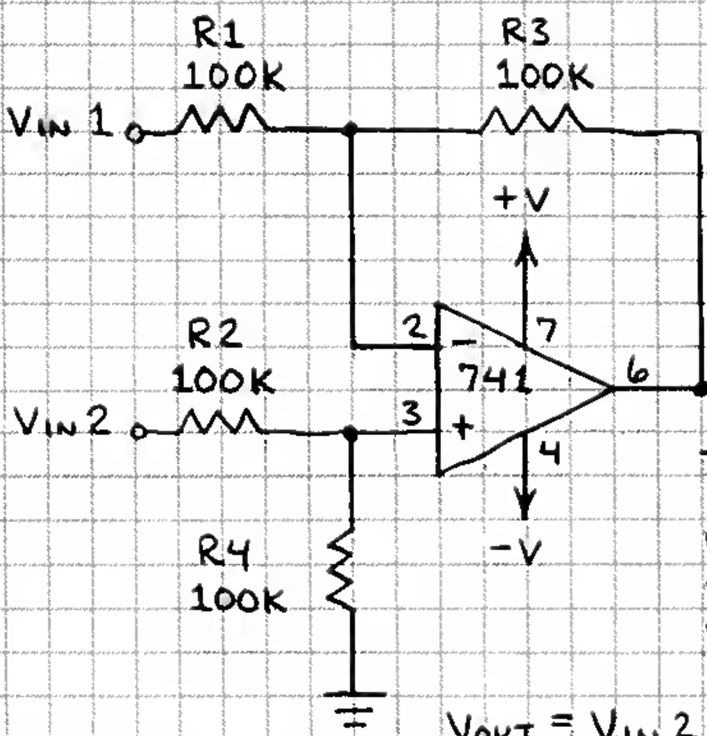
$V_{OUT} = -(V_{IN}1 + V_{IN}2)$

THE OUTPUT OF THE SUMMING AMPLIFIER IS THE SUM OF THE INPUT VOLTAGES. THE SUM OF THE INPUTS SHOULD NOT EXCEED ±V LESS A VOLT OR TWO. OK TO ADD MORE INPUTS. (USE 10K RESISTOR TO PIN 2 FOR EACH INPUT.) THE CIRCUIT BELOW PRESERVES THE POLARITY OF VIN:



$V_{OUT} = V_{IN}1 + V_{IN}2$

DIFFERENCE AMPLIFIER



V= ±5 V TO ±15 V

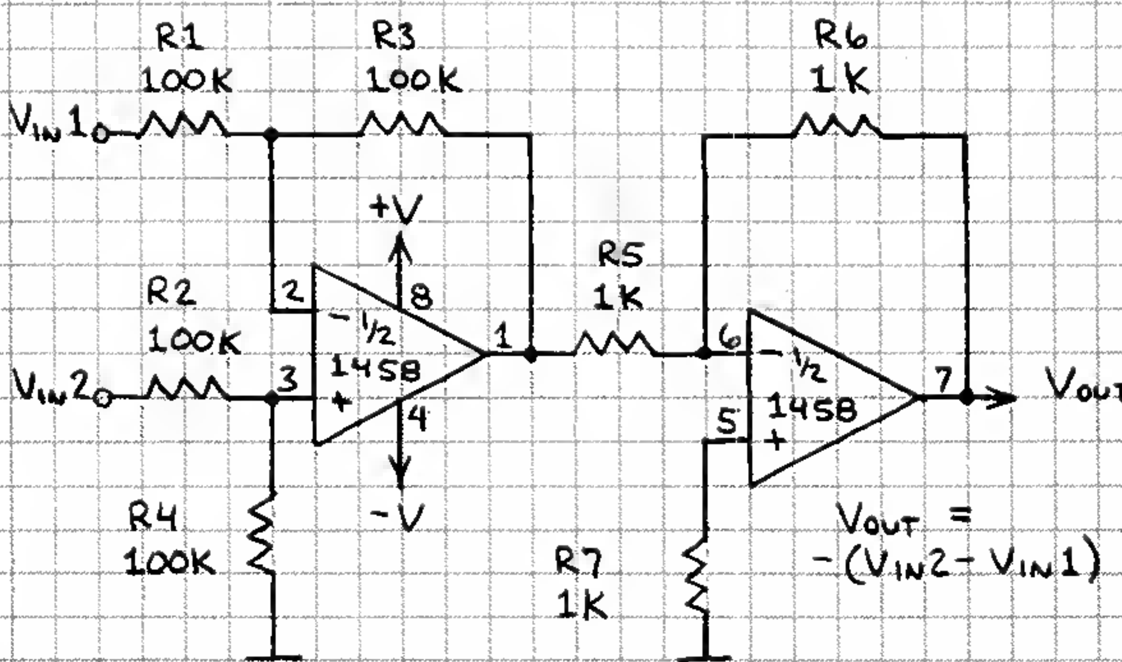
FOR TEST BELOW V = ±10 V.

TEST RESULT:

$V_{IN}1$ = 0.9 V
$V_{IN}2$ = 5.0 V
V_{OUT} = 4.1 V

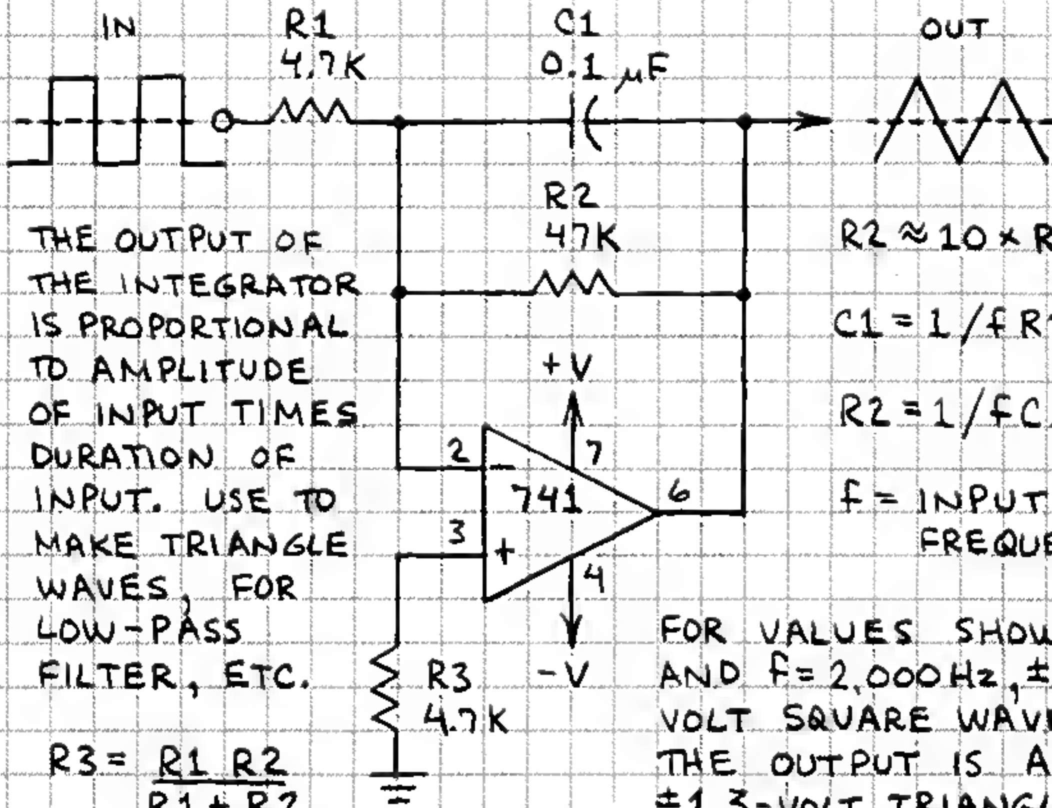
$V_{OUT} = V_{IN}2 - V_{IN}1$

THE OUTPUT OF THE DIFFERENCE AMPLIFIER IS $V_{IN}2 - V_{IN}1$. THE INPUT VOLTAGES SHOULD NOT EXCEED ± V. THE CIRCUIT BELOW REVERSES THE POLARITY OF $V_{IN}2 - V_{IN}1$:



$V_{OUT} = -(V_{IN}2 - V_{IN}1)$

DUAL-SUPPLY INTEGRATOR



THE OUTPUT OF THE INTEGRATOR IS PROPORTIONAL TO AMPLITUDE OF INPUT TIMES DURATION OF INPUT. USE TO MAKE TRIANGLE WAVES, FOR LOW-PASS FILTER, ETC.

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

$R2 \approx 10 \times R1$

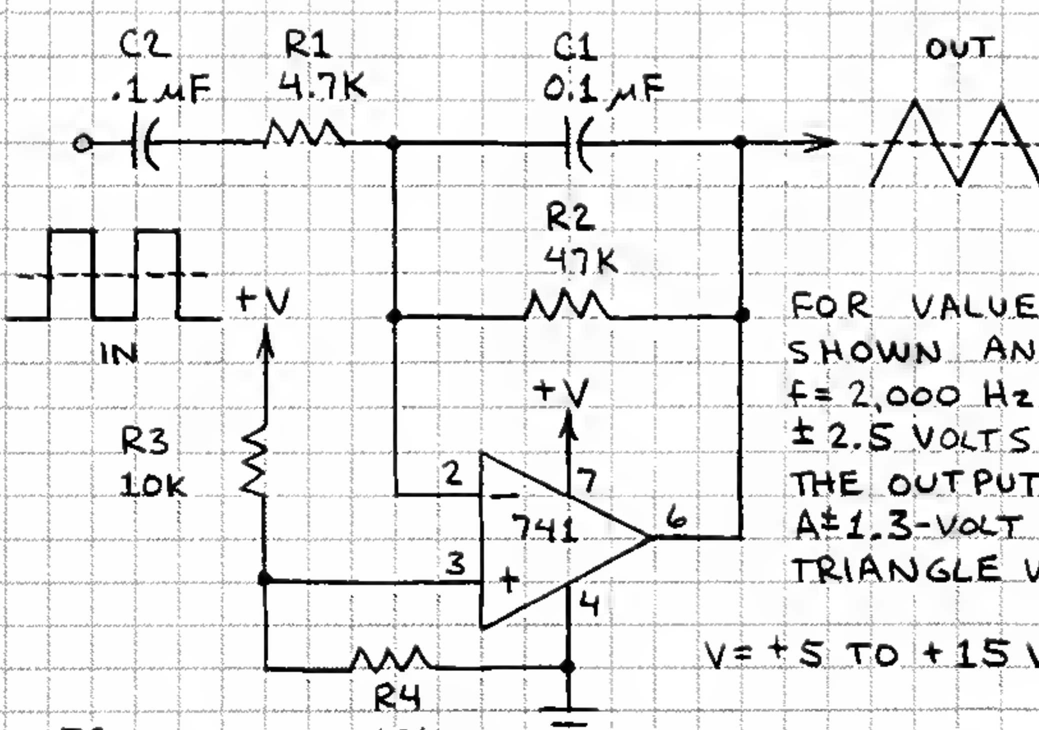
$C1 = 1/fR2$

$R2 = 1/fC1$

f = INPUT FREQUENCY

FOR VALUES SHOWN AND f = 2,000 Hz, ±2.5-VOLT SQUARE WAVE, THE OUTPUT IS A ±1.3-VOLT TRIANGLE.

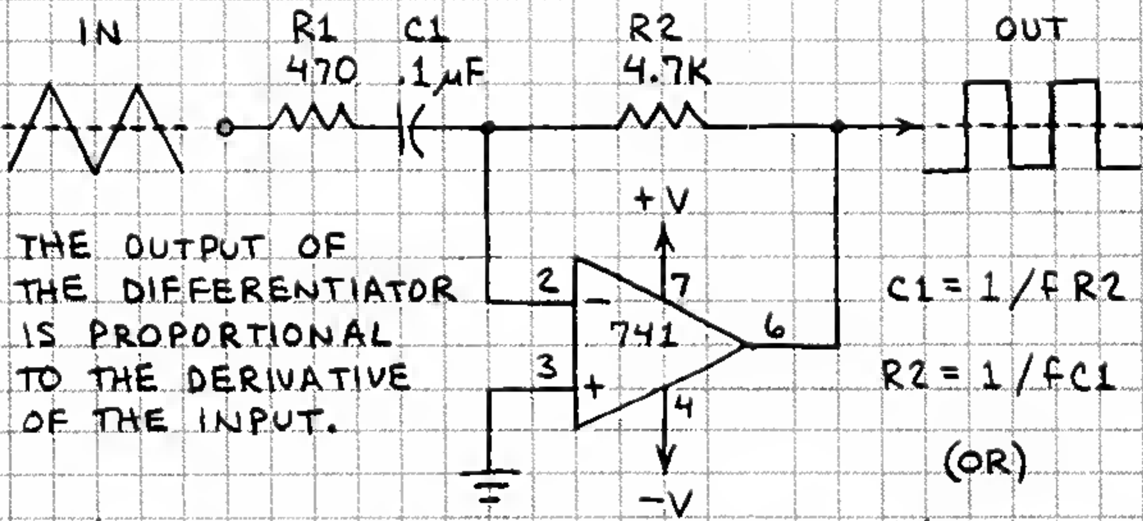
SINGLE-SUPPLY INTEGRATOR



FOR VALUES SHOWN AND f = 2,000 Hz, ± 2.5 VOLTS, THE OUTPUT IS A ±1.3-VOLT TRIANGLE WAVE.

V = +5 TO +15 V

DUAL-SUPPLY DIFFERENTIATOR



THE OUTPUT OF THE DIFFERENTIATOR IS PROPORTIONAL TO THE DERIVATIVE OF THE INPUT.

$C1 = 1/fR2$

$R2 = 1/fC1$

(OR)

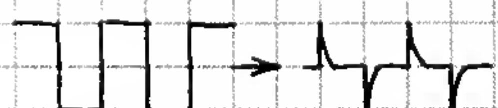
$1/f = R2C1$

V = ±5 V TO ±15 V

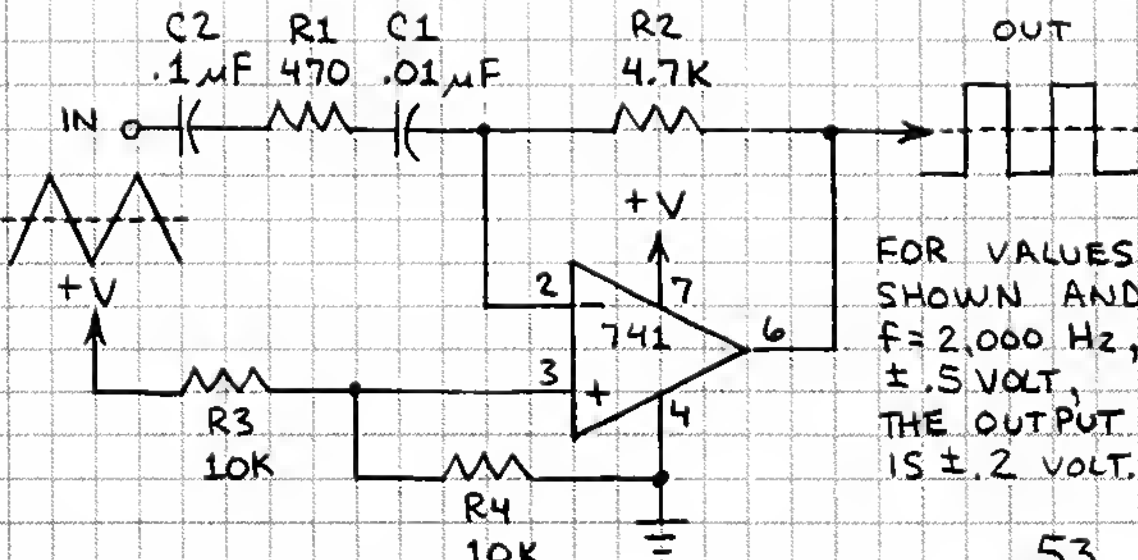
FOR VALUES SHOWN AND f = 2,000 Hz, ±2.5-VOLT TRIANGLE WAVE, THE OUTPUT IS A ±10-VOLT SQUARE WAVE.

THE DIFFERENTIATOR WILL TRANSFORM A SQUARE WAVE INTO PULSES:

f = 2,000 Hz, V = ±10 V
IN = ±0.5 V, OUT = ±7 V

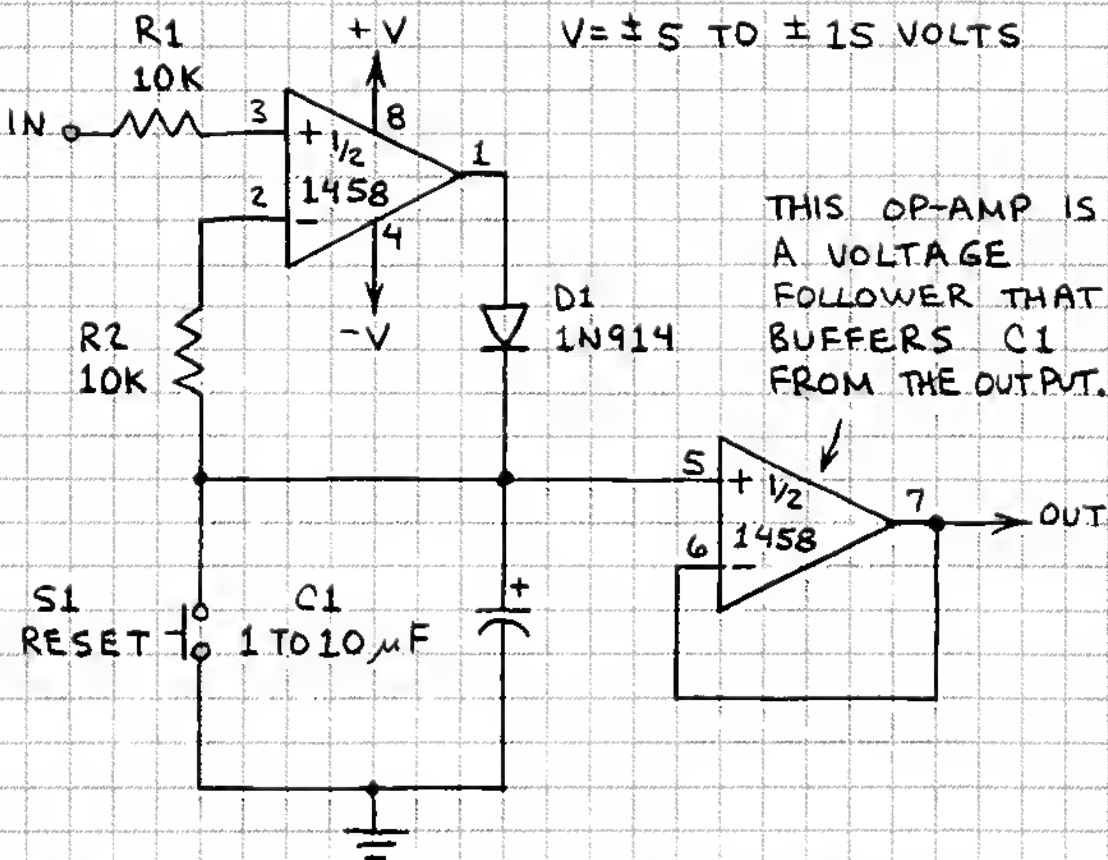


SINGLE-SUPPLY DIFFERENTIATOR

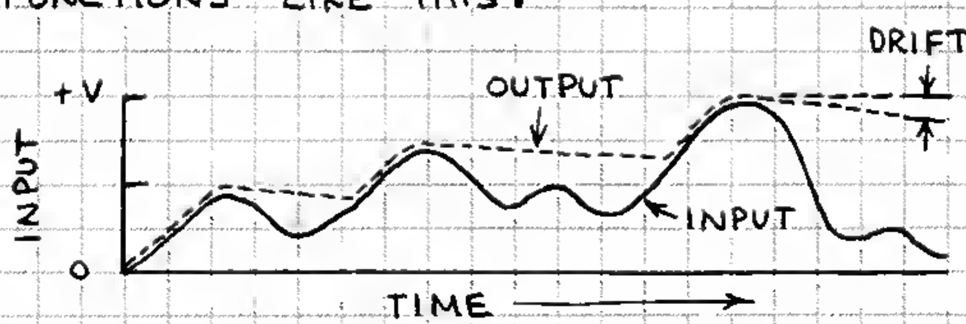


FOR VALUES SHOWN AND f = 2,000 Hz, ±.5 VOLT, THE OUTPUT IS ±.2 VOLT.

PEAK DETECTOR

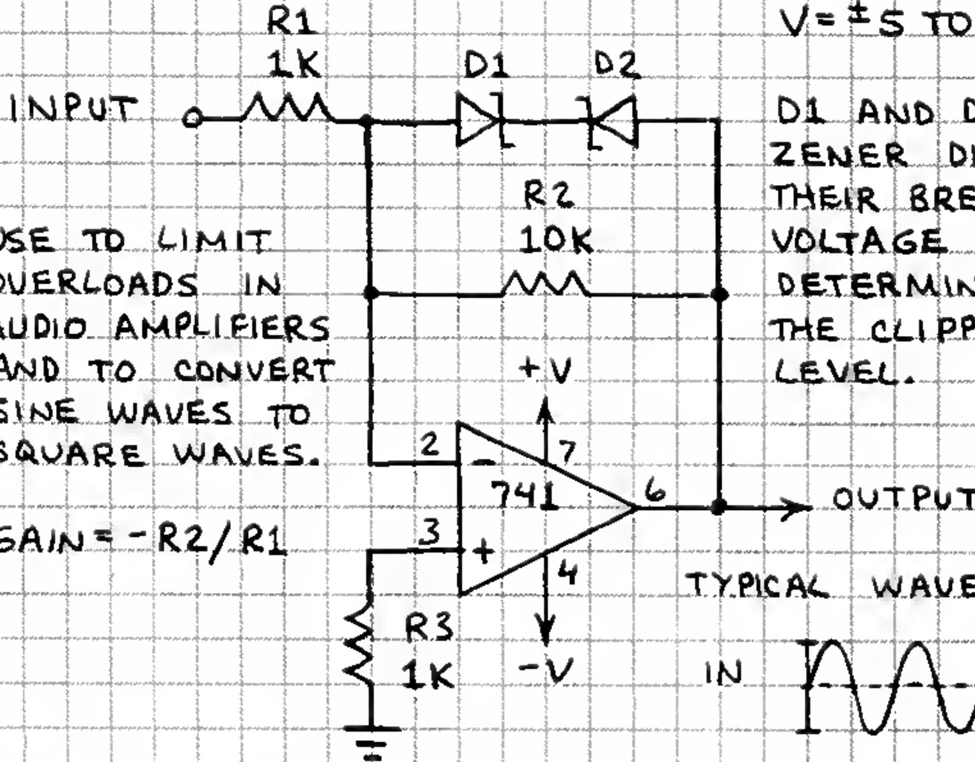


THIS CIRCUIT FOLLOWS AN INCOMING VOLTAGE SIGNAL AND STORES THE MAXIMUM VOLTAGE IN C1. PRESS S1 TO DISCHARGE C1 AND RESET CIRCUIT. CONNECT A VOLTMETER FROM OUTPUT TO GROUND TO MEASURE THE PEAK VOLTAGE STORED IN C1. THE CIRCUIT FUNCTIONS LIKE THIS:



NOTE HOW THE OUTPUT FOLLOWS THE PRECEEDING HIGH (PEAK) INPUT. ALSO NOTE THAT THE CHARGE ON C1 WILL GRADUALLY LEAK AWAY. C1 IN THE TEST CIRCUIT FELL 10 MILLIVOLTS / SECOND.

INVERTING CLIPPER



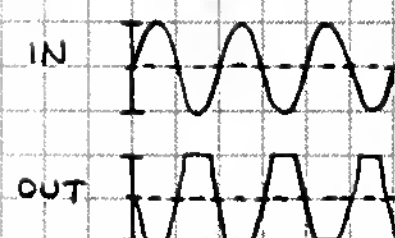
V= ±5 TO ±15 V

D1 AND D2 ARE ZENER DIODES. THEIR BREAKDOWN VOLTAGE IS WHAT DETERMINES THE CLIPPING LEVEL.

USE TO LIMIT OVERLOADS IN AUDIO AMPLIFIERS AND TO CONVERT SINE WAVES TO SQUARE WAVES.

GAIN = -R2/R1

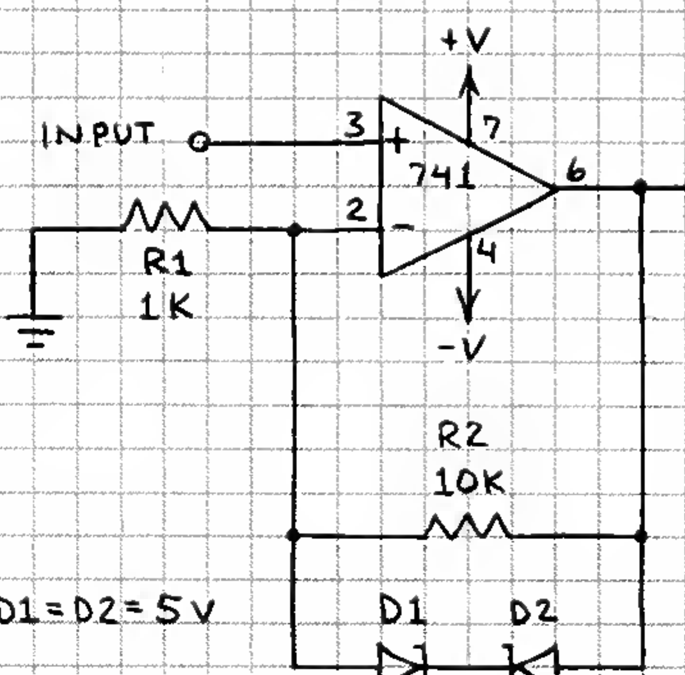
TYPICAL WAVEFORMS:



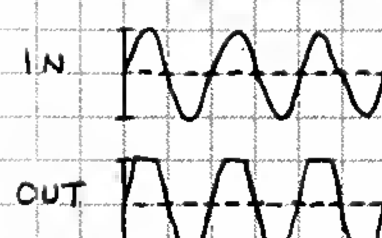
VALUES SHOWN GIVE -(×10) GAIN. D1=D2=5 VOLTS.

NON-INVERTING CLIPPER

V= ±5 TO ±15 V



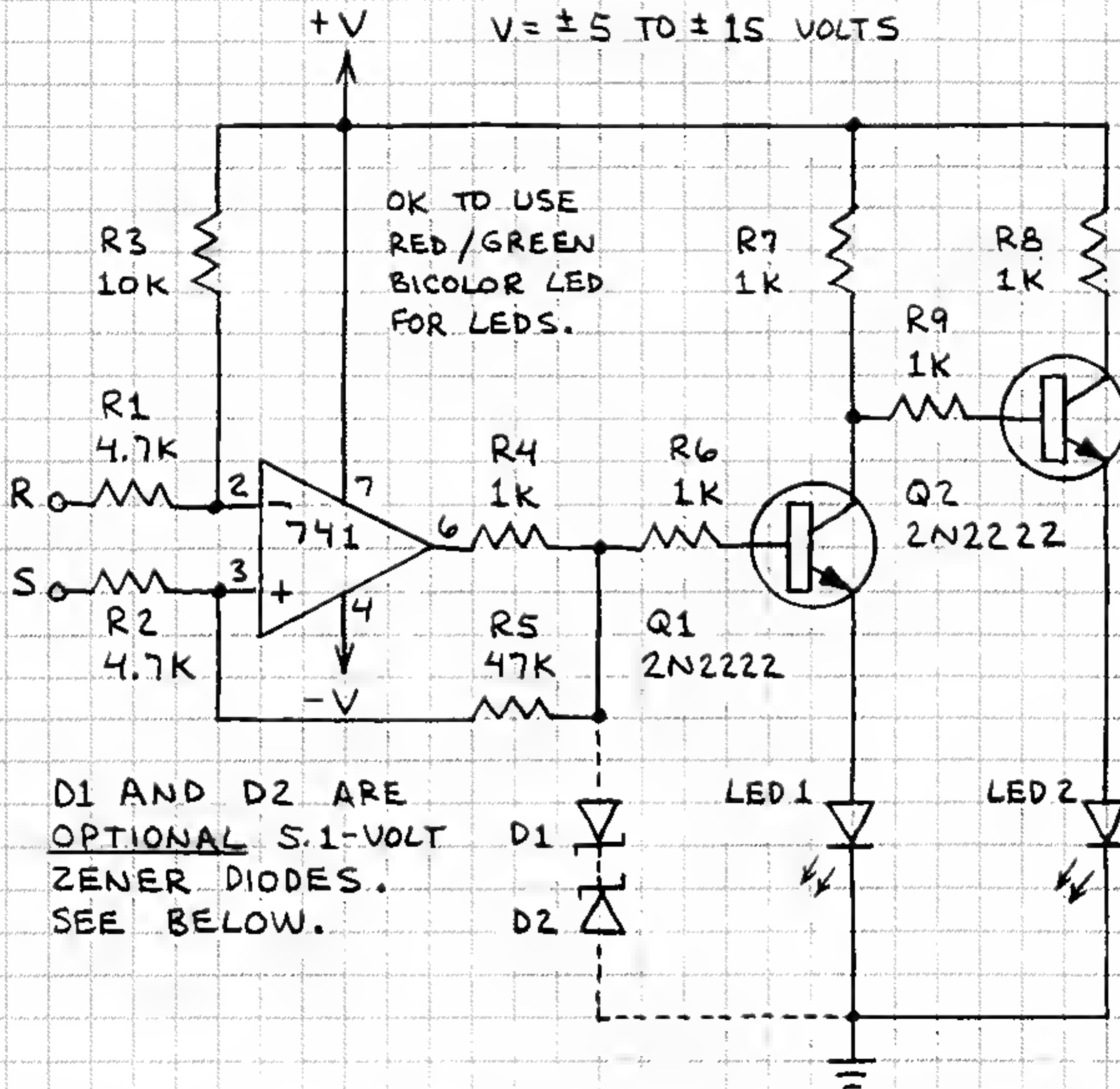
TYPICAL WAVEFORMS



D1=D2=5V

GAIN = 1 + R2/R1
VALUES SHOWN GIVE ×11 GAIN.

BISTABLE RS FLIP-FLOP



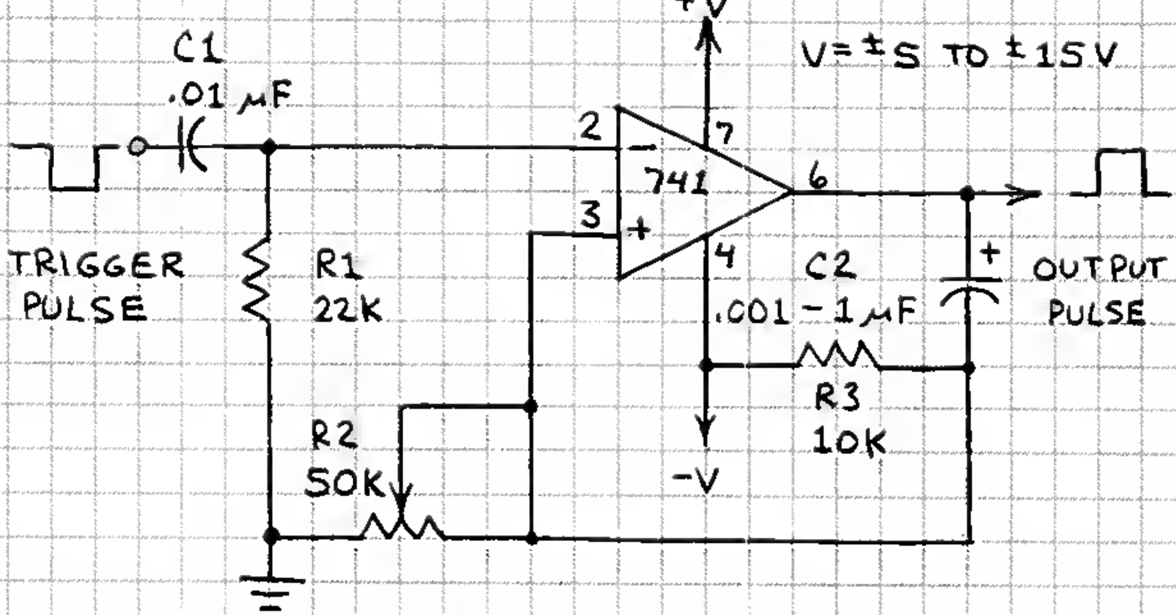
THIS CIRCUIT DEMONSTRATES HOW AN ANALOG CHIP CAN PERFORM A DIGITAL LOGIC FUNCTION. (THE COMPARATOR IS ANOTHER EXAMPLE.) HERE IS THE TRUTH TABLE:

INPUT		LED	
R	S	1	2
GND	+V	ON	OFF
GND	-V	OFF	ON
+V	GND	OFF	ON
-V	GND	ON	OFF

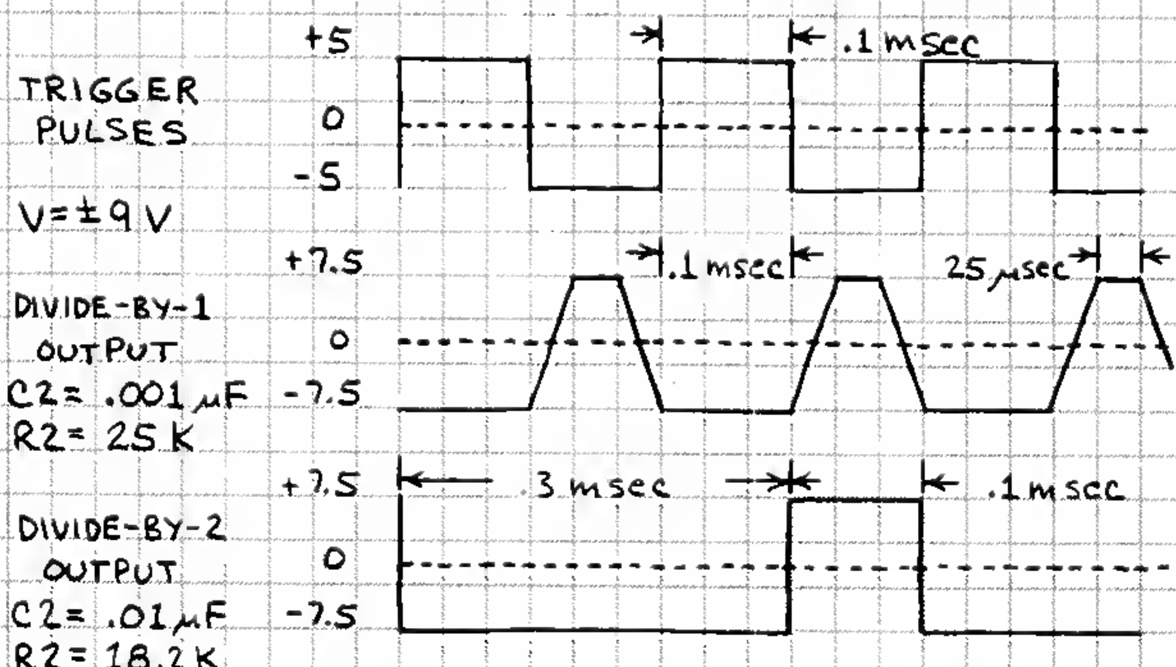
← THESE OUTPUTS HAVE MEMORY AND HOLD THEIR STATE EVEN WHEN S INPUT FLOATS. (arrows point to the first two rows)

USE D1 AND D2 TO LIMIT OUTPUT LEVEL.

MONOSTABLE MULTIVIBRATOR



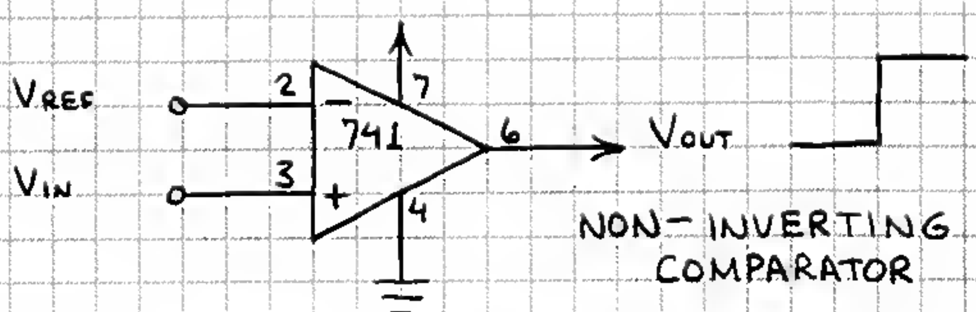
A NEGATIVE TRIGGER PULSE CAUSES THE OP-AMP OUTPUT TO SWING FROM LOW TO HIGH FOR A TIME APPROXIMATELY EQUAL TO R2 × C2. USE TO DIVIDE AN INCOMING SIGNAL AND TO CONVERT AN IRREGULAR INPUT PULSE TO A UNIFORM OUTPUT PULSE. TYPICAL RESULTS:



NOTE: USE THE 555 FOR MORE VERSATILITY.

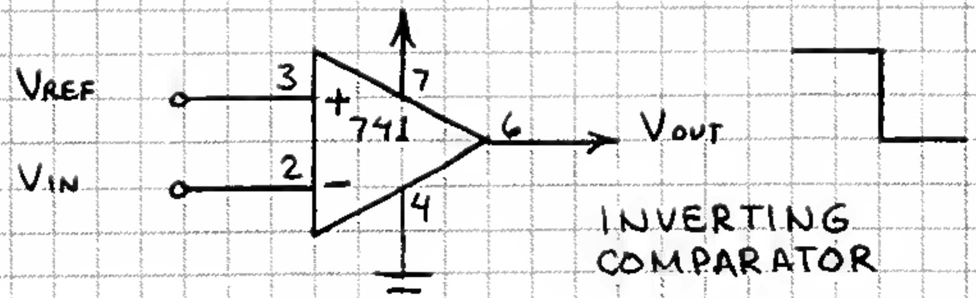
BASIC COMPARATOR

A COMPARATOR IS AN ANALOG CIRCUIT THAT MONITORS TWO INPUT VOLTAGES. ONE VOLTAGE IS CALLED THE REFERENCE VOLTAGE (V_{REF}) AND THE OTHER IS CALLED THE INPUT VOLTAGE (V_{IN}). WHEN V_{IN} RISES ABOVE OR FALLS BELOW V_{REF}, THE OUTPUT OF THE COMPARATOR CHANGES STATES. SOME CIRCUITS (LIKE THE 339) ARE DESIGNED SPECIFICALLY AS COMPARATORS. DUE TO ITS VERY HIGH OPEN-LOOP GAIN, AN OP-AMP WITHOUT A FEEDBACK RESISTOR CAN FUNCTION AS A COMPARATOR.



NON-INVERTING COMPARATOR

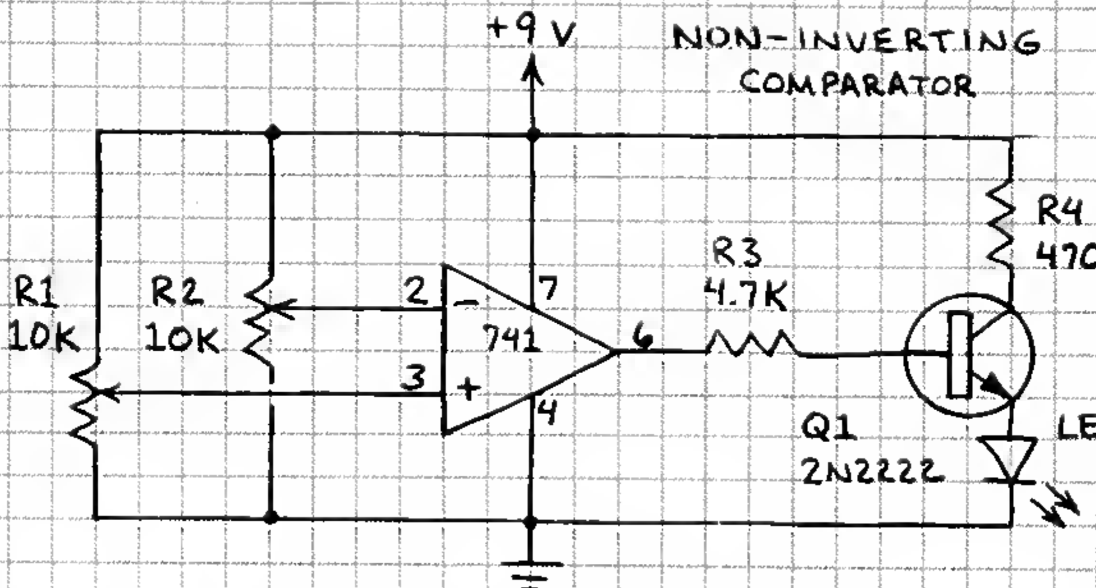
WHEN V_{IN} EXCEEDS V_{REF}, OUTPUT SWITCHES FROM LOW TO HIGH.



INVERTING COMPARATOR

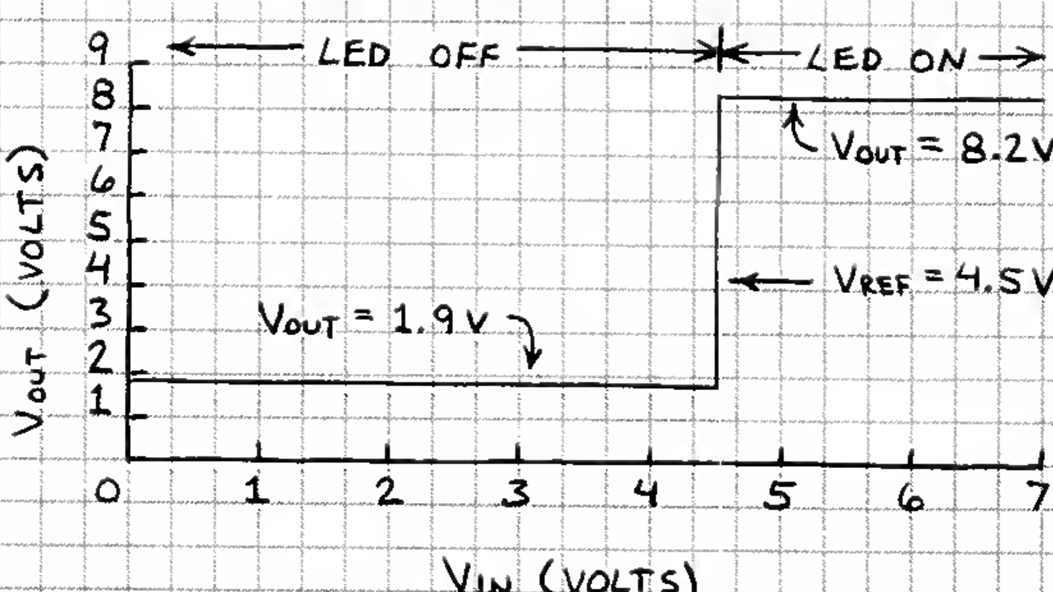
WHEN V_{IN} EXCEEDS V_{REF}, OUTPUT SWITCHES FROM HIGH TO LOW.

BASIC COMPARATOR (CONT.)

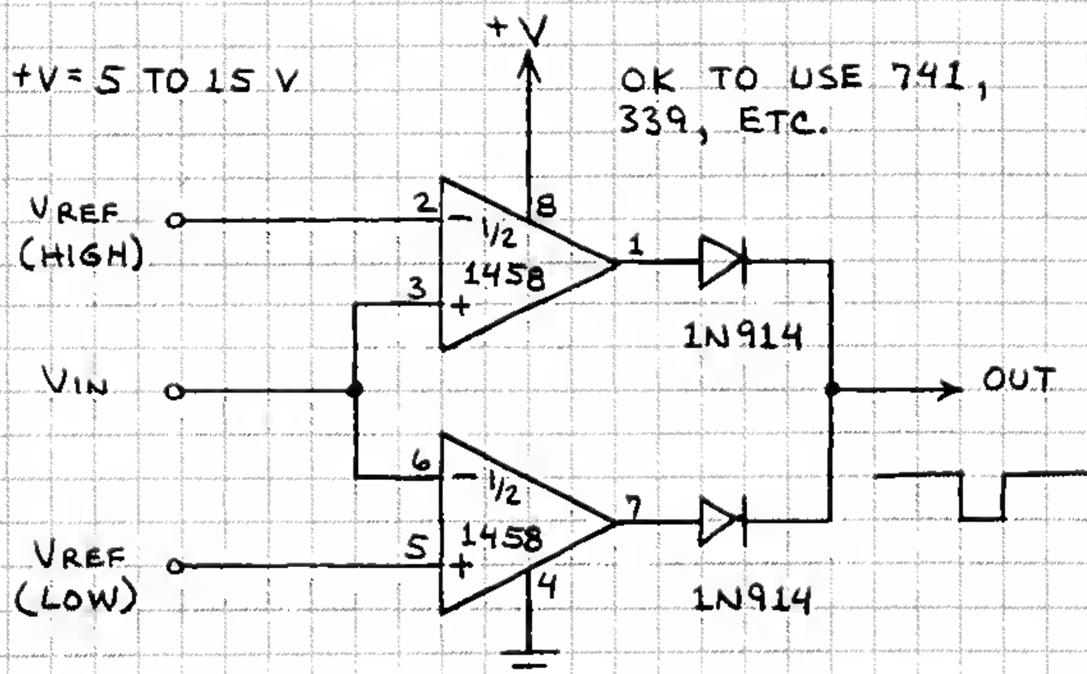


BUILD THIS SIMPLE CIRCUIT ON A PLASTIC BREADBOARD TO LEARN BASICS OF THE COMPARATOR. R1 AND R2 FUNCTION AS VOLTAGE DIVIDERS THAT SUPPLY A RANGE OF VOLTAGES TO BOTH 741 INPUTS. Q1 SWITCHES CURRENT TO THE LED WHEN THE OUTPUT OF THE 741 GOES HIGH. THE CIRCUIT WORKS LIKE THIS:

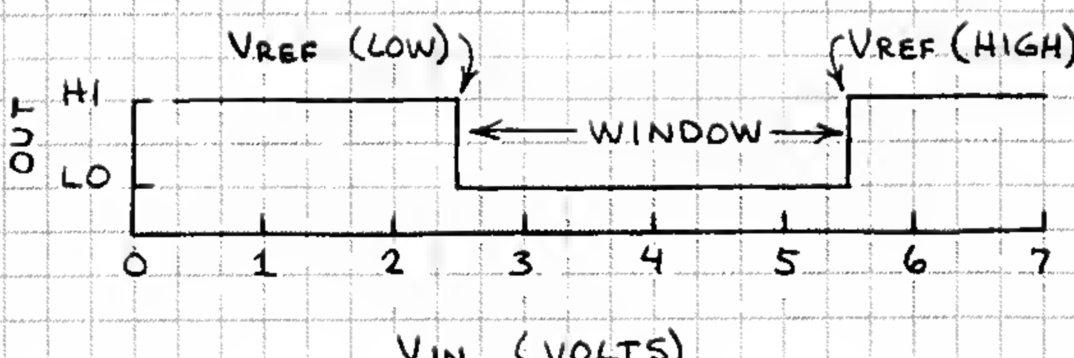
ASSUME R2 IS SET TO ITS CENTER POSITION TO GIVE V_{REF} = 4.5 VOLTS (9V/2 = 4.5V). R1 THEN CONTROLS V_{IN}.



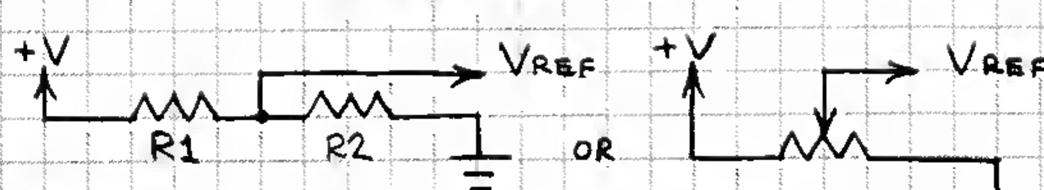
BASIC WINDOW COMPARATOR



THIS IS AMONG THE MOST VERSATILE OF COMPARATOR CIRCUITS. ASSUME VREF (HIGH) IS 5.5 VOLTS AND VREF (LOW) IS 2.5 VOLTS. CIRCUIT THEN OPERATES LIKE THIS:



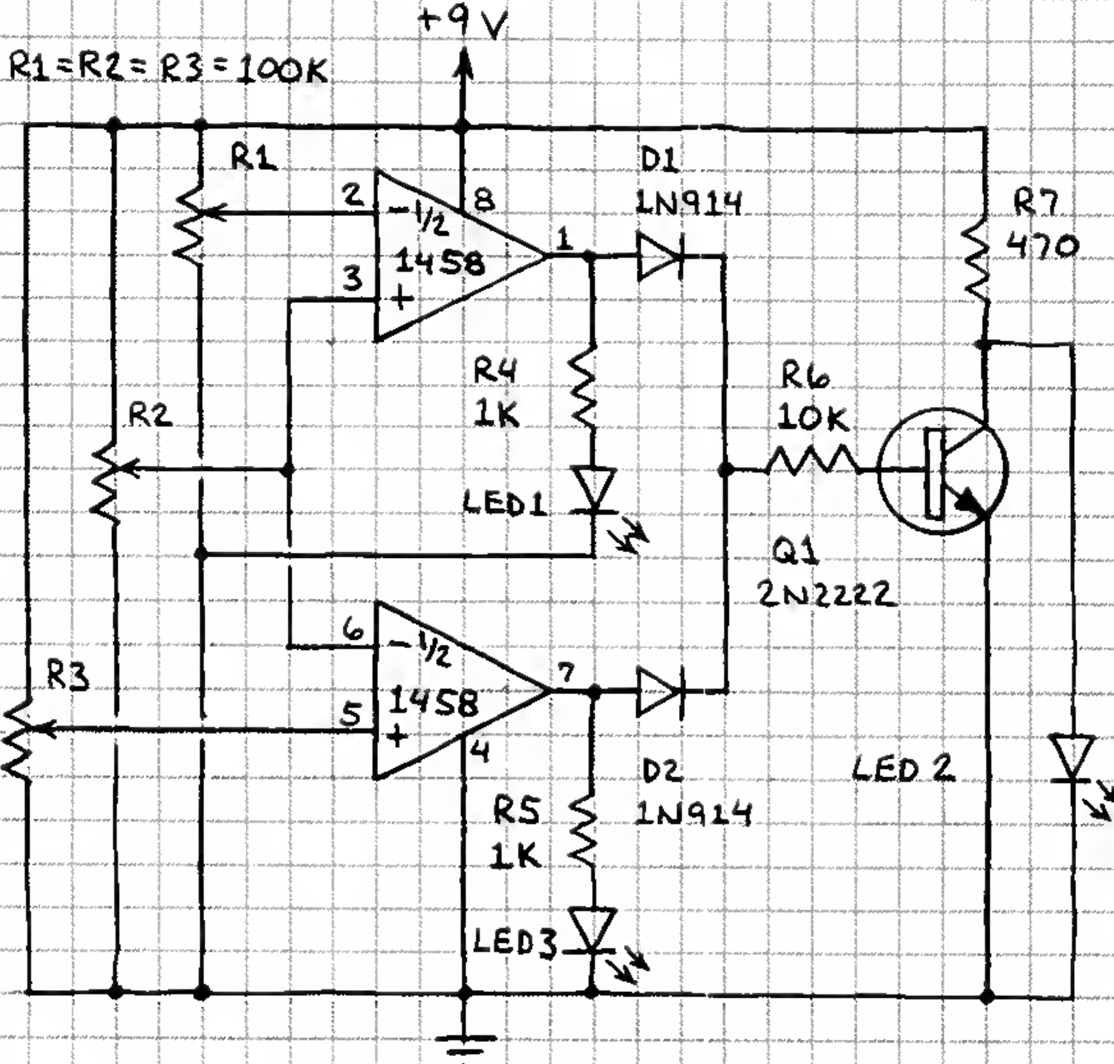
ONE OR BOTH REFERENCE VOLTAGES CAN BE SUPPLIED BY A VOLTAGE DIVIDER:



$$V_{REF} = +V\left(\frac{R2}{R1 + R2}\right)$$

V_{REF} VARIES

WINDOW COMPARATOR (CONT.)



BUILD THIS CIRCUIT ON A BREADBOARD TO LEARN BASICS OF THE WINDOW COMPARATOR. USE VOLTMETER TO SET V_{REF} HIGH (R1) AND V_{REF} LOW (R3). (CONNECT PROBES ACROSS PIN 2 OF 1458 AND GROUND; ADJUST R1. REPEAT FOR PIN 5 AND GROUND; ADJUST R3.) ADJUST R2 TO VARY V_{IN}.

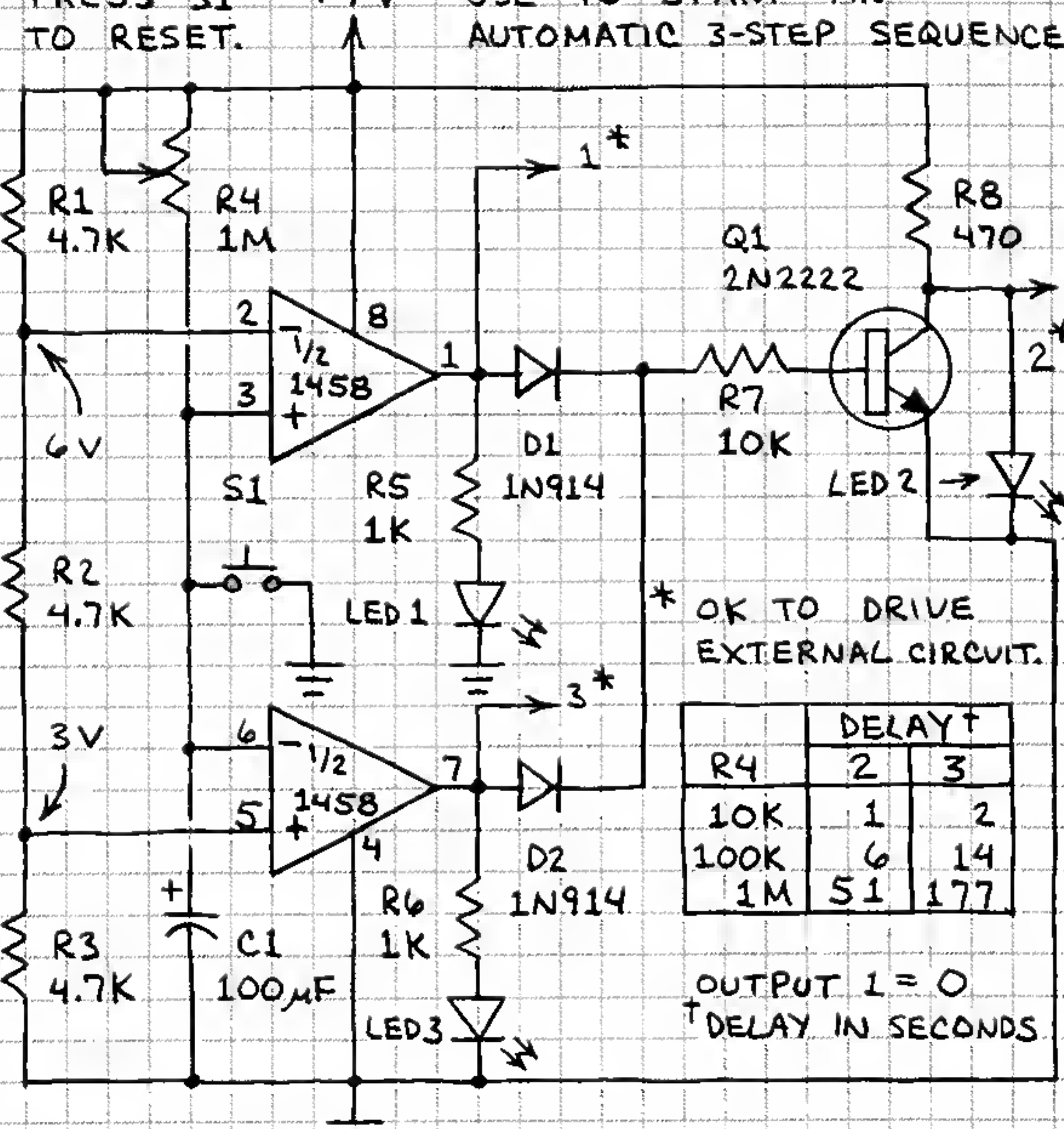
V_{IN} AT OR ABOVE V_{REF} HIGH: LED 1 ON
V_{IN} WITHIN WINDOW: LED 2 ON
V_{IN} AT OR BELOW V_{REF} LOW: LED 3 ON

WHEN V_{IN} IS BELOW 0.6 VOLT, BOTH LED 1 AND LED 3 SWITCH ON.

3-STEP SEQUENCER

PRESS S1 TO RESET.

USE TO START AN AUTOMATIC 3-STEP SEQUENCE



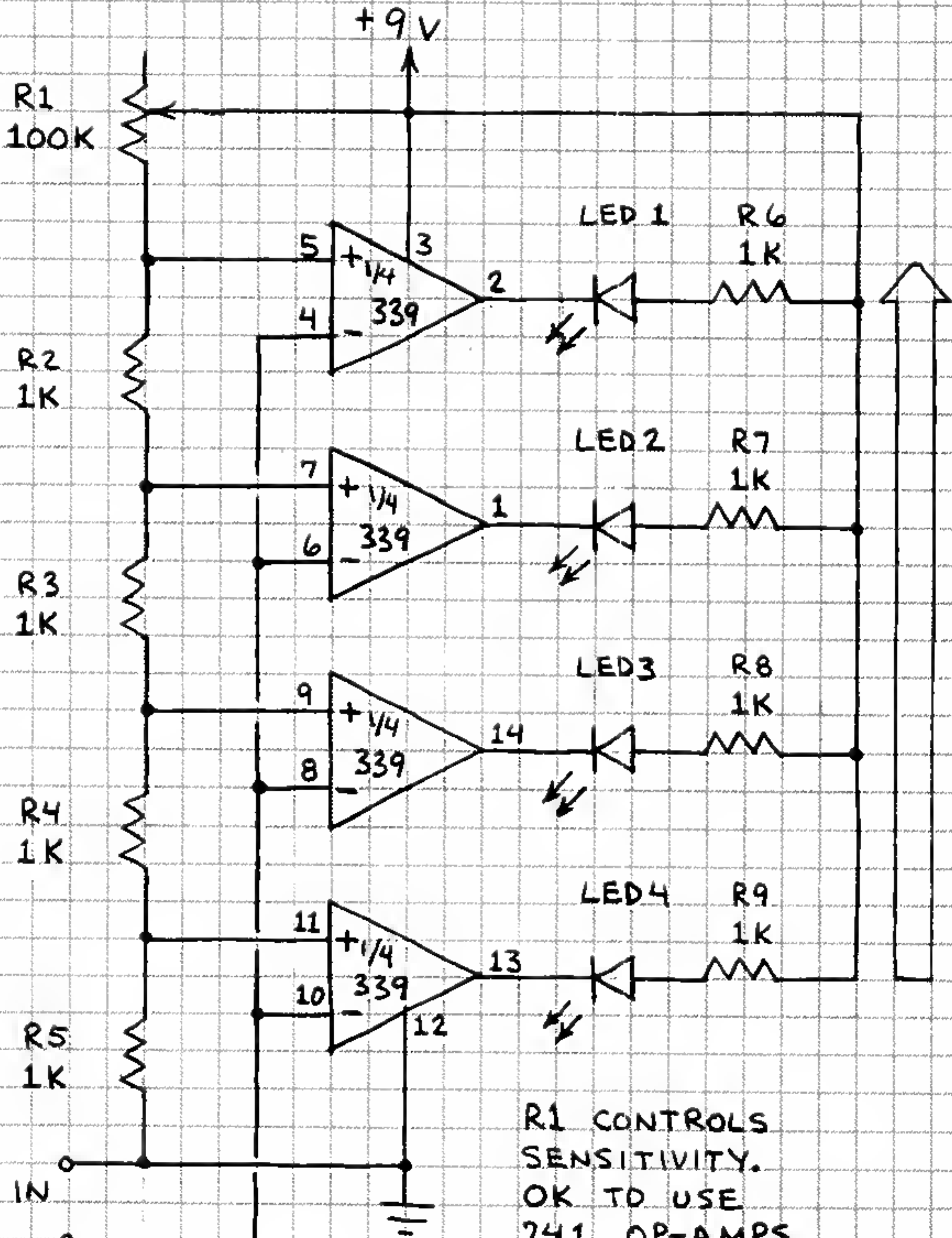
	DELAY†	
R4	2	3
10K	1	2
100K	6	14
1M	51	177

OUTPUT 1 = 0

† DELAY IN SECONDS

THIS IS A WINDOW COMPARATOR THAT SUPPLIES A 3-STEP SEQUENCE OF OUTPUT SIGNALS. PRESSING S1 DISCHARGES C1 AND LIGHTS LED 1 (AND LED 2 BRIEFLY). C1 THEN CHARGES THROUGH R4. AS CHARGE ON C1 PASSES 3 AND 6 VOLTS, LEDS 2 AND 3 GLOW IN SEQUENCE. REDUCE R2 TO BALANCE TIME DELAY SEQUENCE AND REDUCE DELAY TIME. DELAYS SHOWN WILL VARY WITH TOLERANCE OF C1.

BARGRAPH VOLTMETER

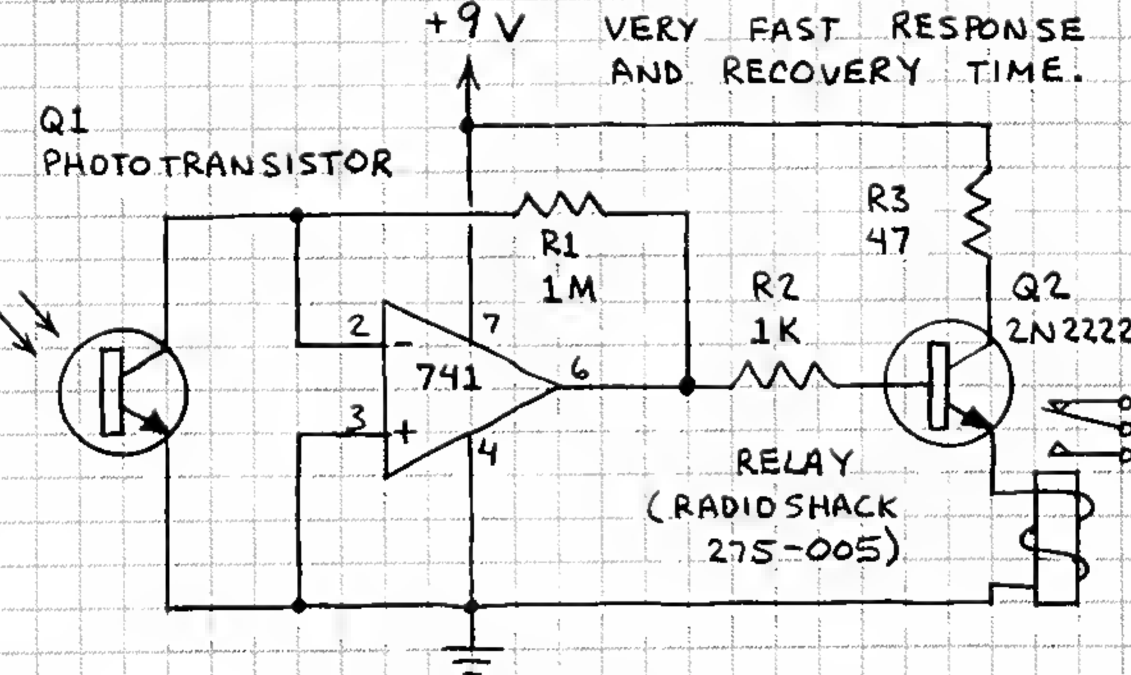


R1 CONTROLS SENSITIVITY. OK TO USE 741 OP-AMPS.

LEDS GLOW IN SEQUENCE AS INPUT VOLTAGE RISES. LEDS ALSO RESPOND TO CHANGE IN RESISTANCE AT INPUT. TOUCH INPUTS WITH FINGER TO OBSERVE. CONNECT CdS CELL ACROSS INPUTS TO MAKE LIGHTMETER.

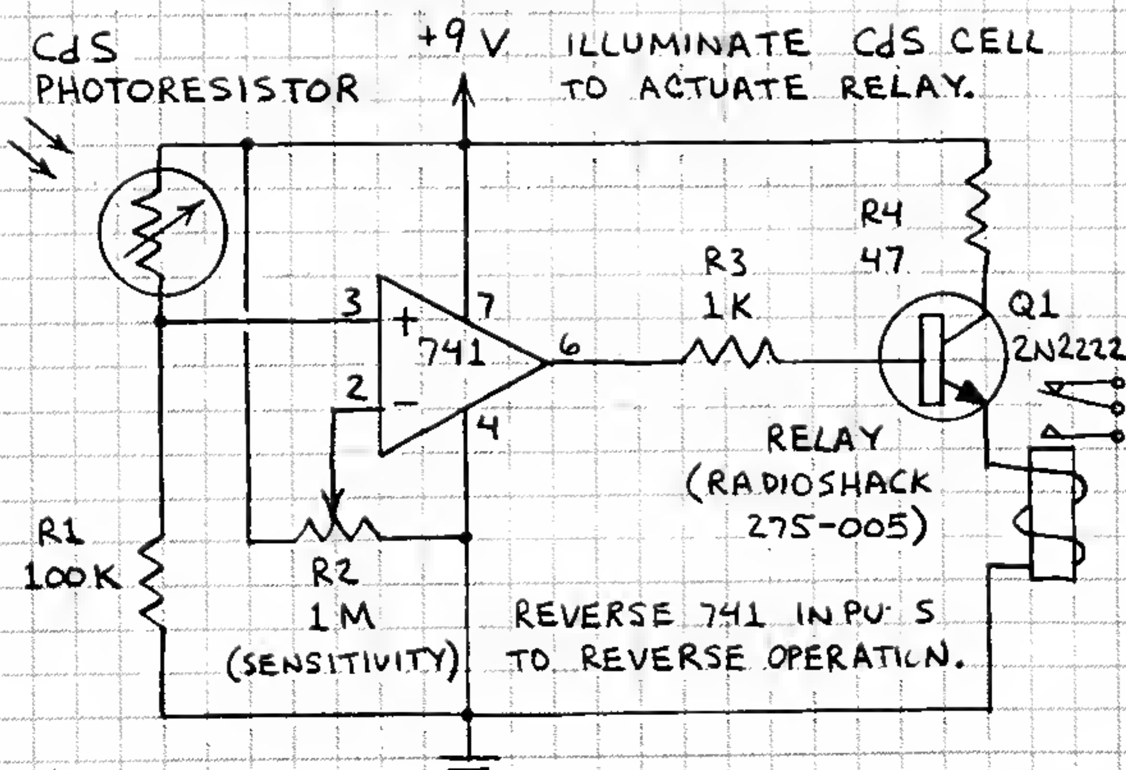
LIGHT-ACTIVATED RELAYS

PHOTOTRANSISTOR:

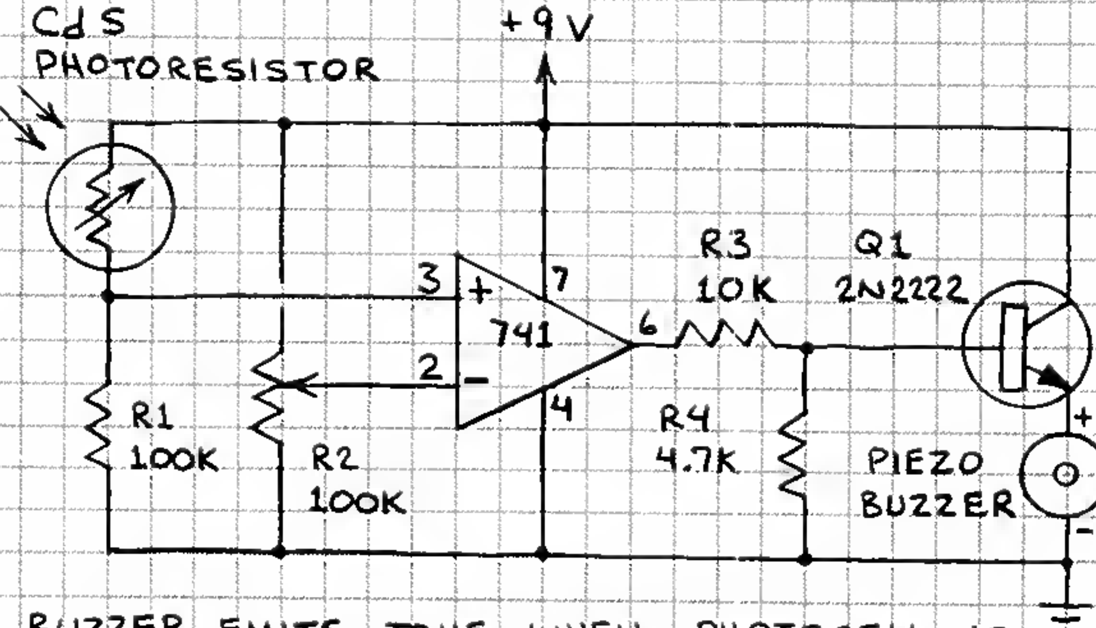


ILLUMINATE Q1 TO ACTIVATE RELAY.

PHOTORESISTOR:

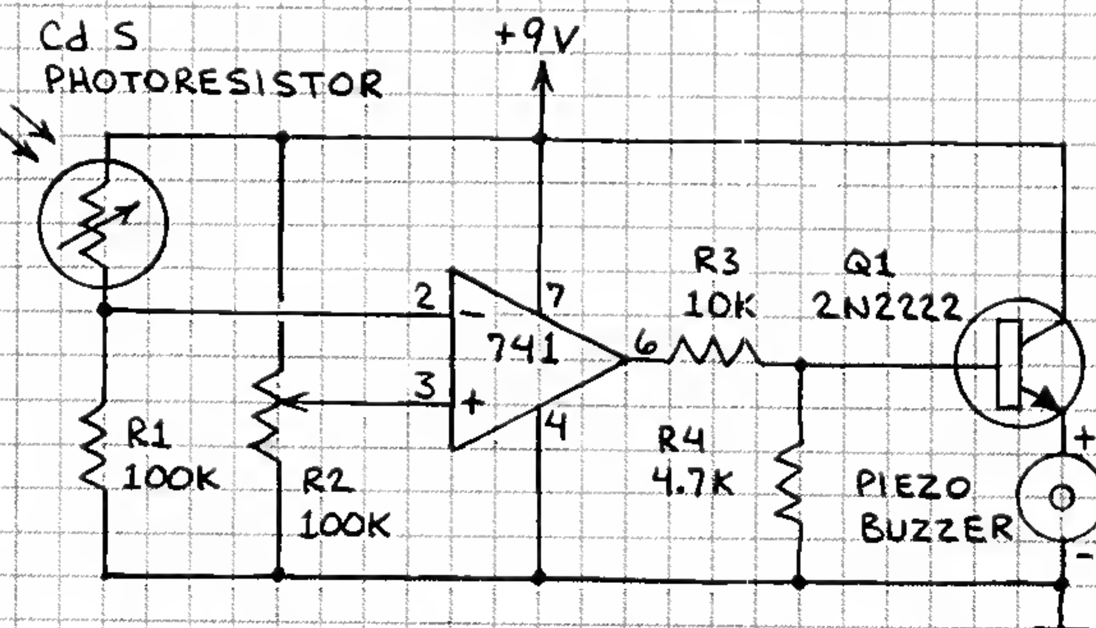


LIGHT-ACTIVATED ALERTER



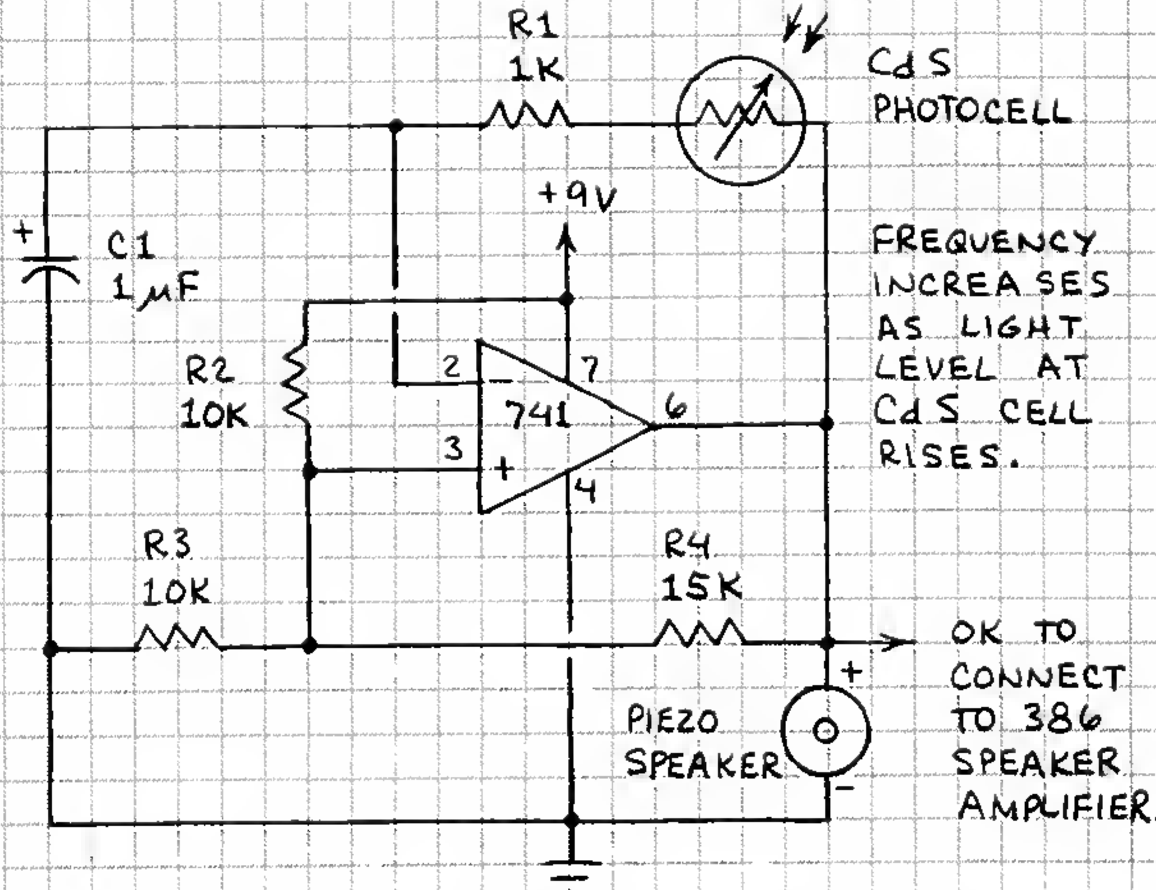
BUZZER EMITS TONE WHEN PHOTOCELL IS ILLUMINATED. R2 CONTROLS SENSITIVITY. R4 KEEPS Q1 OFF UNTIL THE 741 OUTPUT GOES HIGH. USE AS SUN-ACTIVATED WAKEUP ALARM AND OPEN REFRIGERATOR DOOR ALARM.

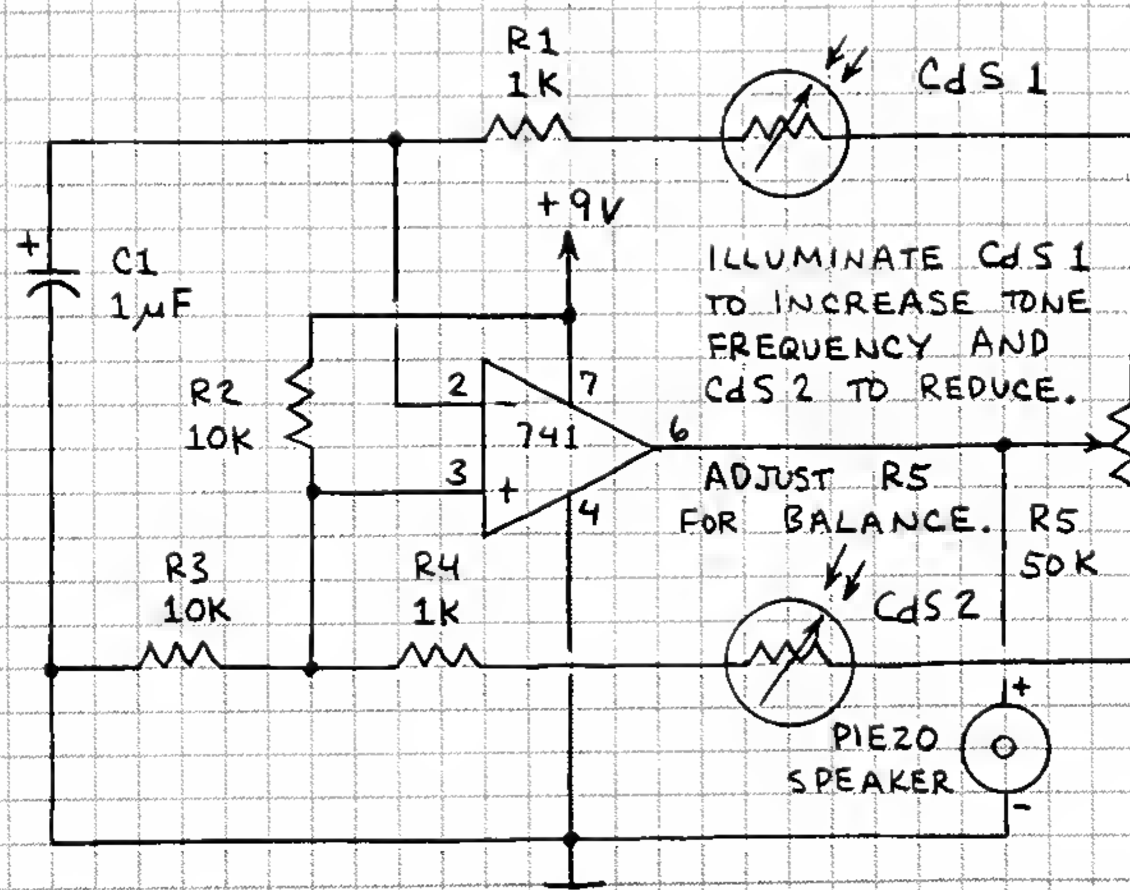
DARK-ACTIVATED ALERTER



IDENTICAL TO ABOVE CIRCUIT EXCEPT INPUTS TO 741 REVERSED. OK TO REPLACE PIEZO BUZZER WITH RELAY.

LIGHT-SENSITIVE OSCILLATORS



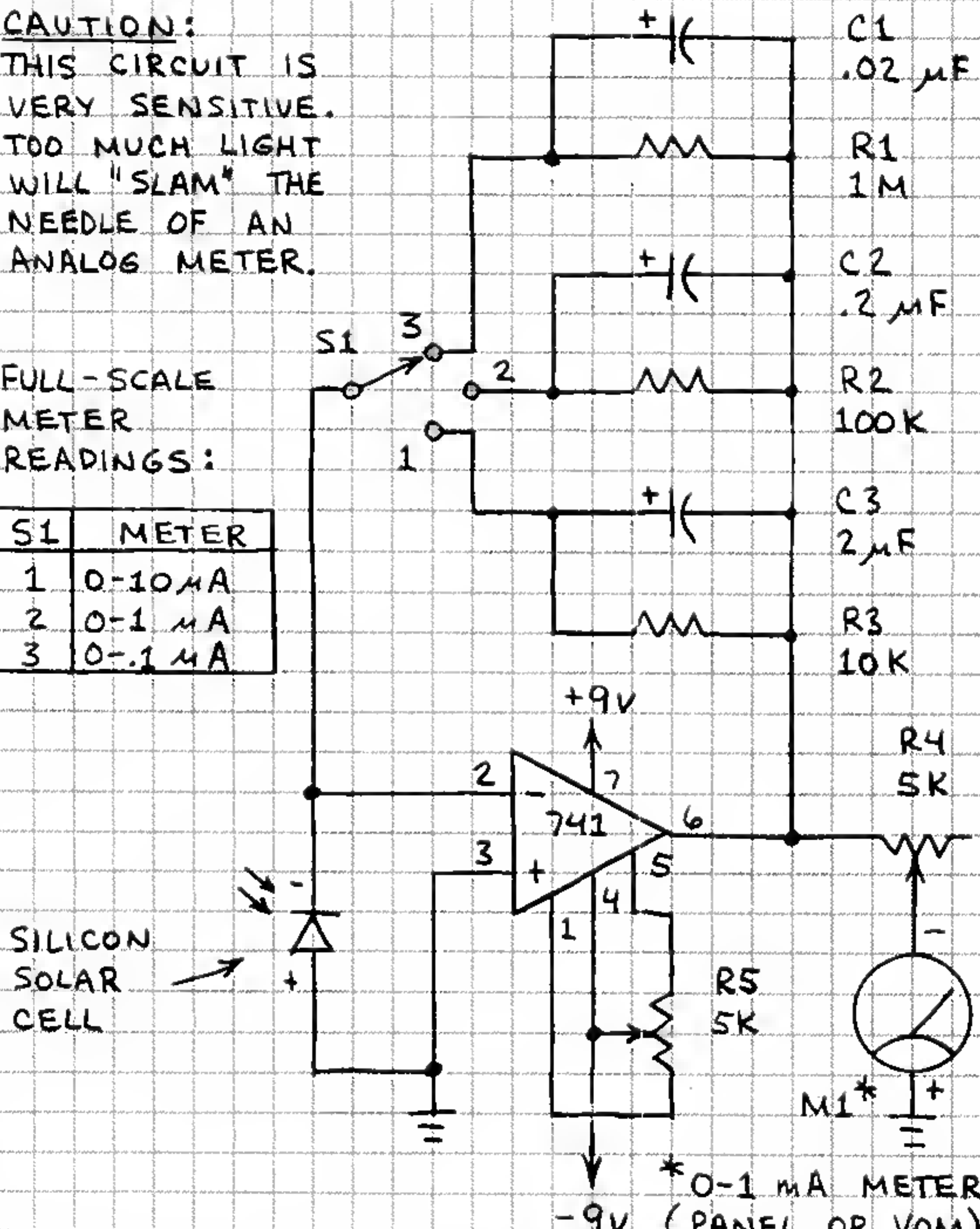


HIGH-SENSITIVITY LIGHT METER

CAUTION:
THIS CIRCUIT IS VERY SENSITIVE. TOO MUCH LIGHT WILL "SLAM" THE NEEDLE OF AN ANALOG METER.

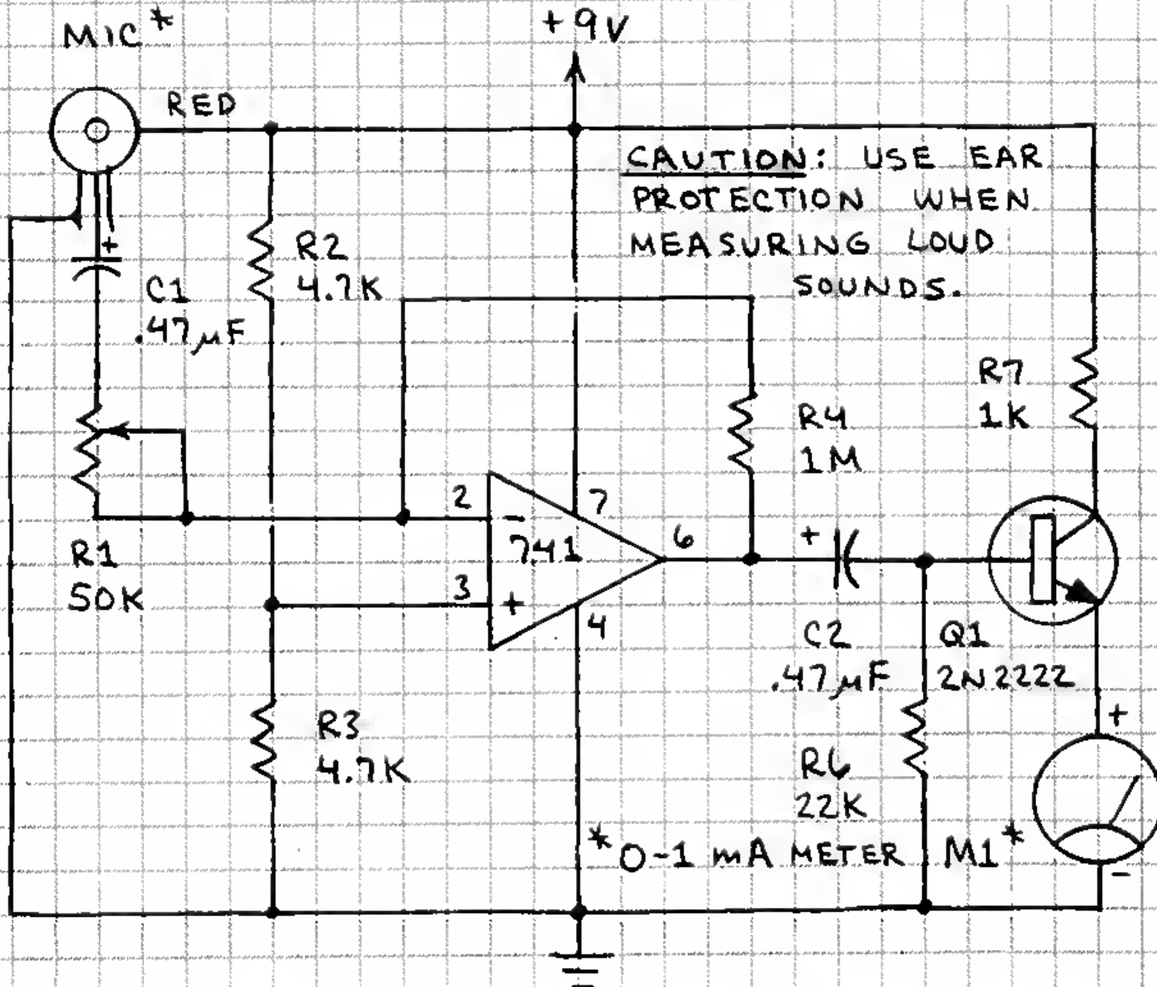
FULL-SCALE METER READINGS:

S1	METER
1	0-10 µA
2	0-1 µA
3	0-.1 µA



THIS CIRCUIT IS BASED UPON THOSE USED IN SOME PRECISION, LABORATORY-QUALITY LIGHT METERS. TO ZERO METER, CONNECT PIN 2 TO GROUND AND ADJUST OFFSET (R5) UNTIL METER READS 0. THEN DISCONNECT PIN 2 FROM GROUND. R4 IS AN OPTIONAL CONTROL FOR ALTERING SENSITIVITY OF THE CIRCUIT.

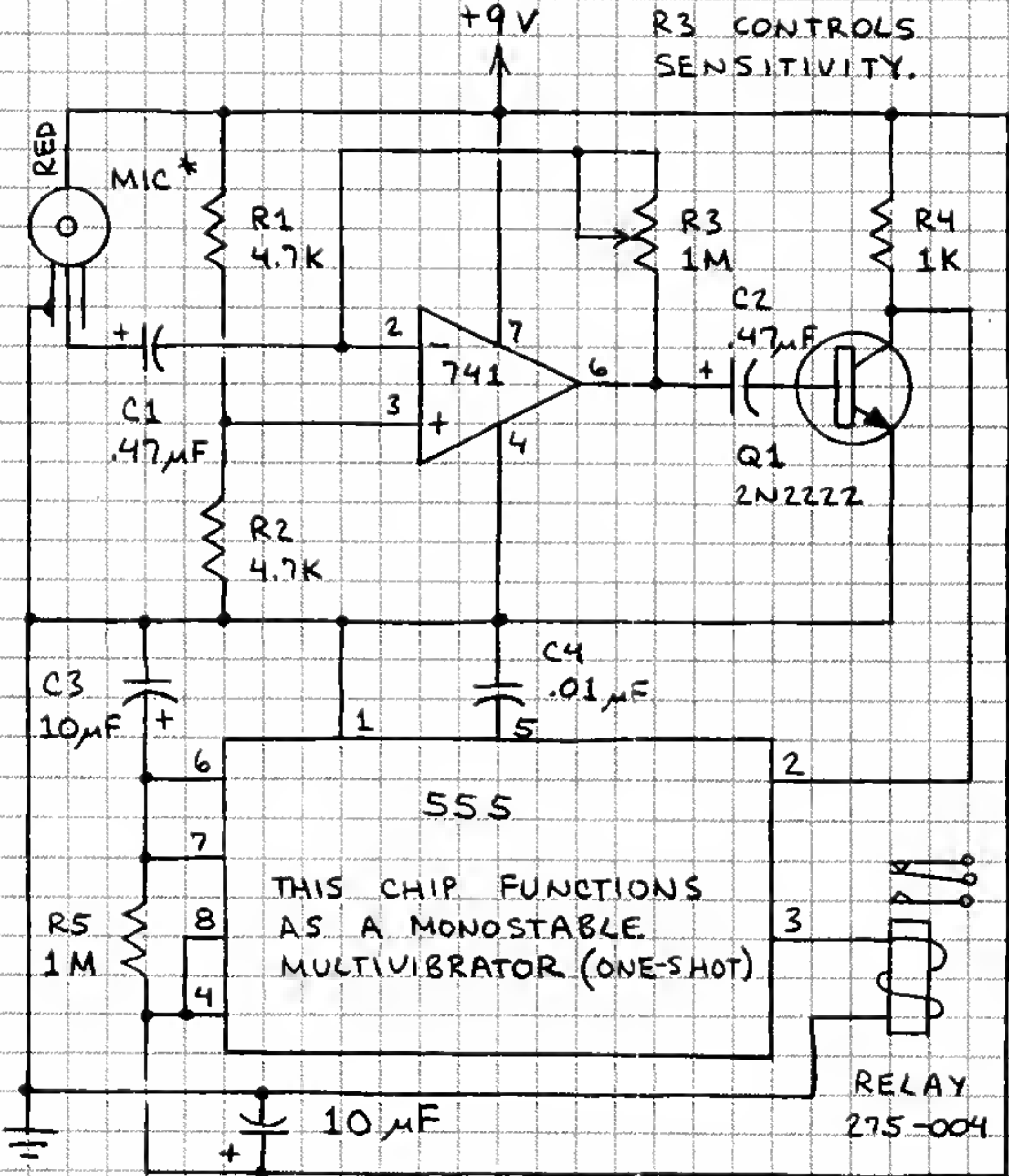
SOUND-LEVEL METER



*MICROPHONE (RADIOSHACK 270-092 OR SIMILAR).

THIS SIMPLE CIRCUIT IS AN EFFECTIVE SOUND-LEVEL METER. R1 CONTROLS THE GAIN OF THE 741 OP-AMP, HENCE THE SENSITIVITY OF THE CIRCUIT. THE METER CAN BE A PANEL METER OR A MULTIMETER SET TO READ CURRENT. THE CIRCUIT WAS TESTED WITH A PIEZO BUZZER THAT EMITTED A 6.5 KHz TONE AT A SOUND PRESSURE OF 90 dB. WHEN THE BUZZER WAS 2" FROM THE MICROPHONE AND R1 WAS SET FOR MAXIMUM GAIN, THE METER INDICATED 1 mA. AT 12" THE OUTPUT FELL TO 0.4 mA. NORMAL SPEECH AT 12" GAVE FLUCTUATING SIGNAL UP TO 10 µA.

SOUND-ACTIVATED RELAY



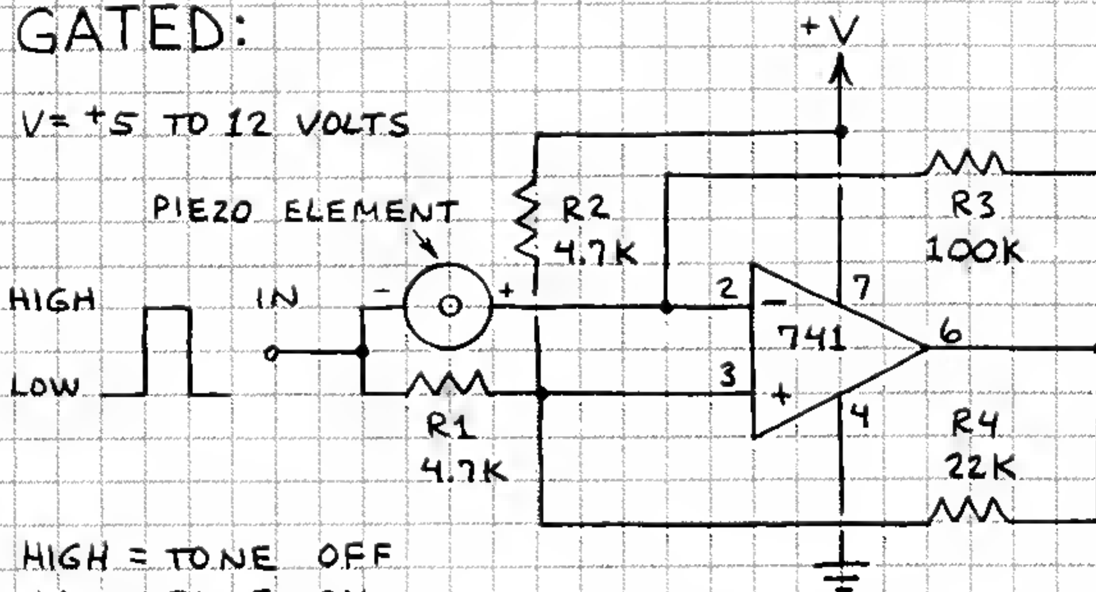
*MICROPHONE (RADIOSHACK 270-092 OR SIMILAR).

THIS CIRCUIT TRIPS RELAY IN RESPONSE TO LOUD SOUND (VOICE, CLAP, ETC.). R5 AND C3 CONTROL TIME RELAY STAYS PULLED IN (VALUES SHOWN GIVE ~12 SECONDS). <u>IMPORTANT</u>: USE 0.1μF CAPACITOR ACROSS POWER SUPPLY PINS OF BOTH THE 741 AND 555. REDUCE RESISTANCE OF R3 TO REDUCE SENSITIVITY.

PIEZO ELEMENT DRIVERS

GATED:

V= +5 TO 12 VOLTS

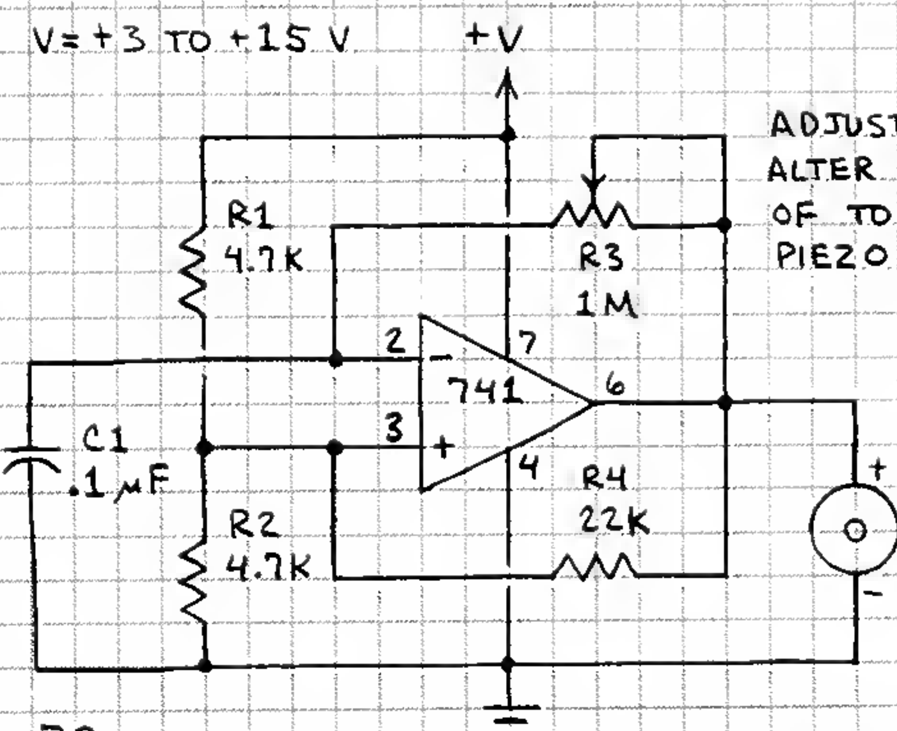


HIGH = TONE OFF
LOW = TONE ON

THIS CIRCUIT IS AN ASTABLE MULTIVIBRATOR IN WHICH A PIEZO ELEMENT DOUBLES AS THE TIMING CAPACITOR AND THE TONE SOURCE. TRIGGER WITH LOGIC SIGNAL OR BY CONNECTING SWITCH FROM INPUT TO GROUND.

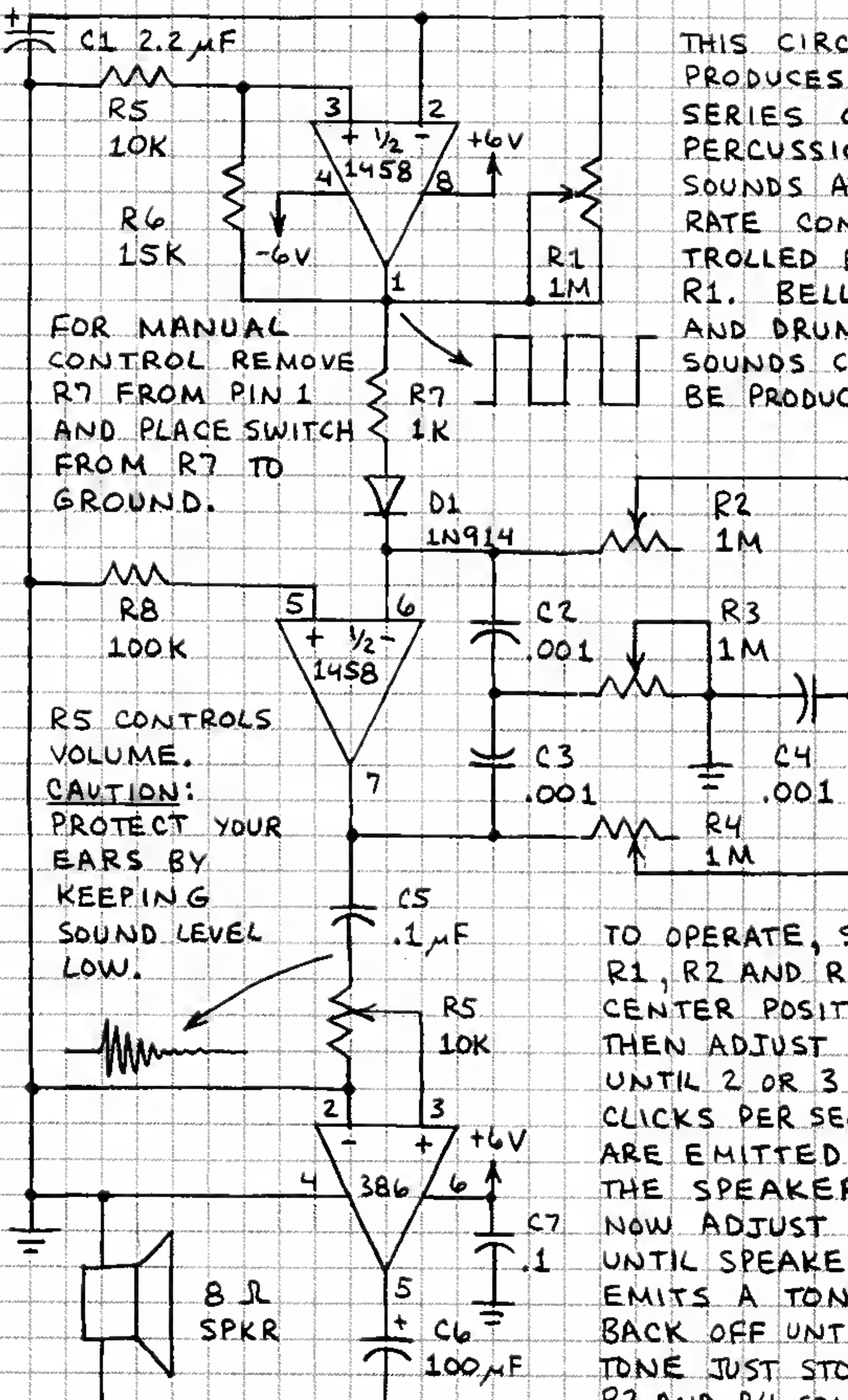
VARIABLE FREQUENCY

V= +3 TO +15 V



ADJUST R3 TO ALTER FREQUENCY OF TONE FROM PIEZO ELEMENT.

PERCUSSION SYNTHESIZER



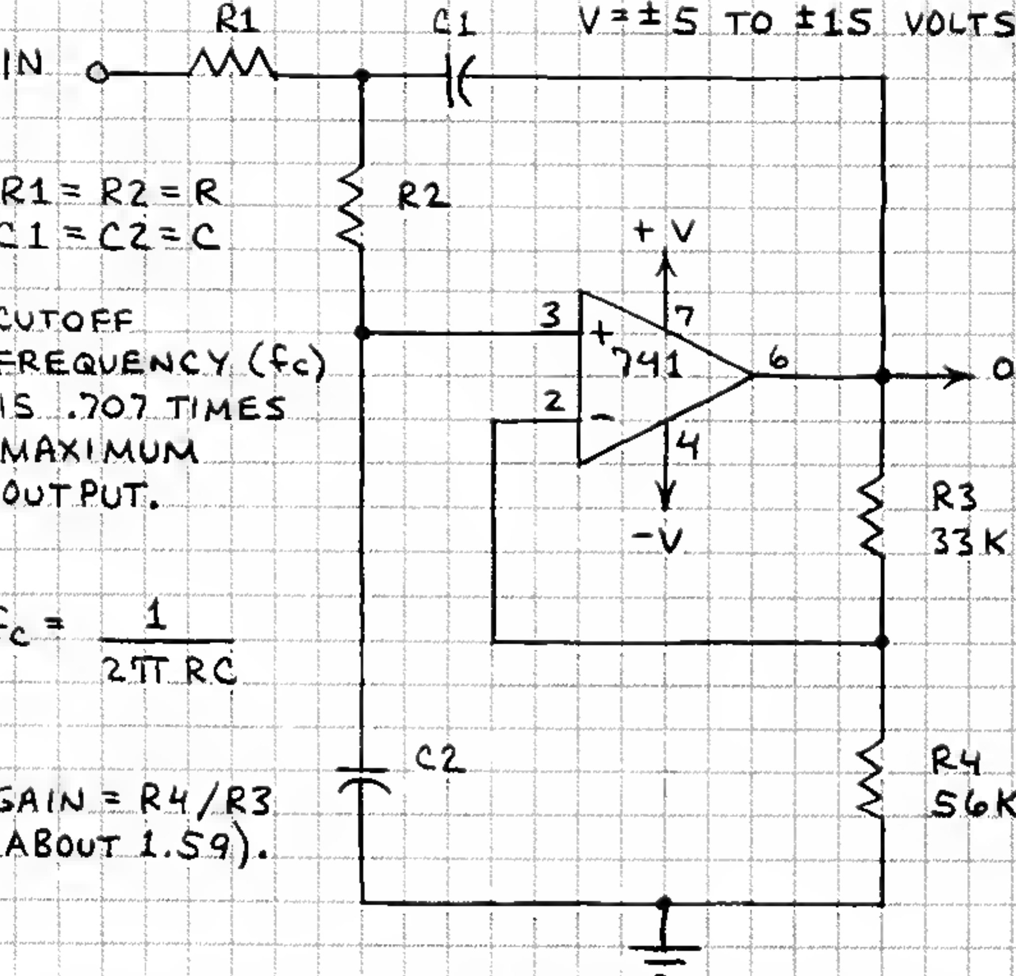
THIS CIRCUIT PRODUCES A SERIES OF PERCUSSION SOUNDS AT A RATE CONTROLLED BY R1. BELL AND DRUM SOUNDS CAN BE PRODUCED.

FOR MANUAL CONTROL REMOVE R7 FROM PIN 1 AND PLACE SWITCH FROM R7 TO GROUND.

R5 CONTROLS VOLUME.
<u>CAUTION</u>: PROTECT YOUR EARS BY KEEPING SOUND LEVEL LOW.

TO OPERATE, SET R1, R2 AND R3 TO CENTER POSITIONS. THEN ADJUST R1 UNTIL 2 OR 3 CLICKS PER SECOND ARE EMITTED BY THE SPEAKER. NOW ADJUST R3 UNTIL SPEAKER EMITS A TONE. BACK OFF UNTIL TONE JUST STOPS. R2 AND R4 CONTROL PITCH.

LOW-PASS FILTER



R1 = R2 = R
C1 = C2 = C

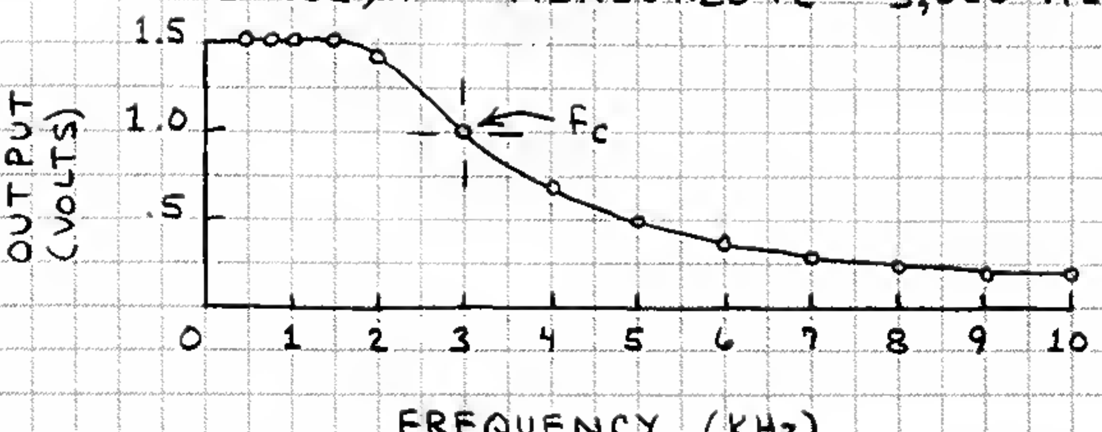
CUTOFF FREQUENCY (f_c) IS .707 TIMES MAXIMUM OUTPUT.

$$f_c = \frac{1}{2\pi RC}$$

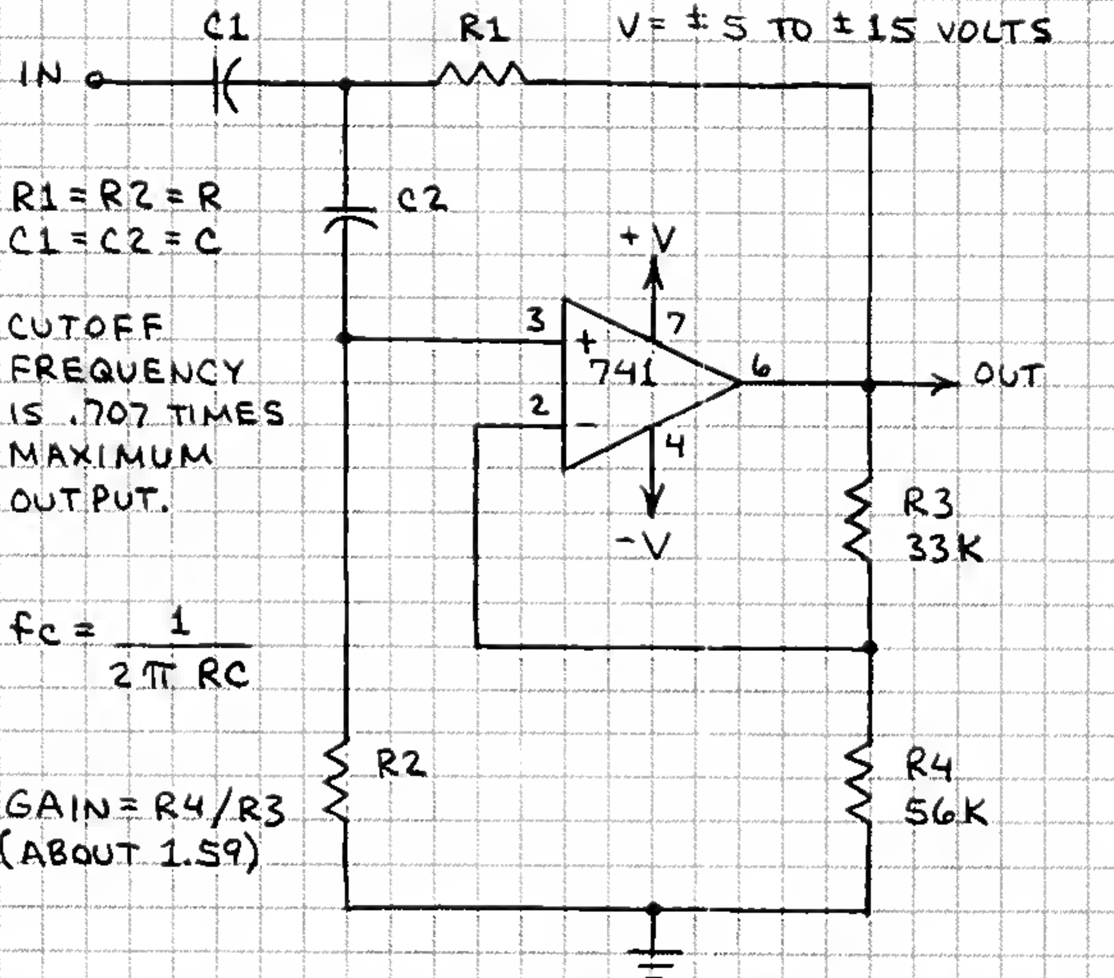
GAIN = R4/R3 (ABOUT 1.59).

THIS IS AN EQUAL COMPONENT SALLEN-KEY FILTER. R3 SHOULD BE .586 × R4. SHOWN BELOW IS RESPONSE OF FILTER WHEN INPUT WAS A 1-VOLT SINE WAVE:

R = 4,700 Ω   CALCULATED f_c = 3,386 Hz
C = .01 µF   MEASURED f_c = 3,000 Hz



HIGH-PASS FILTER



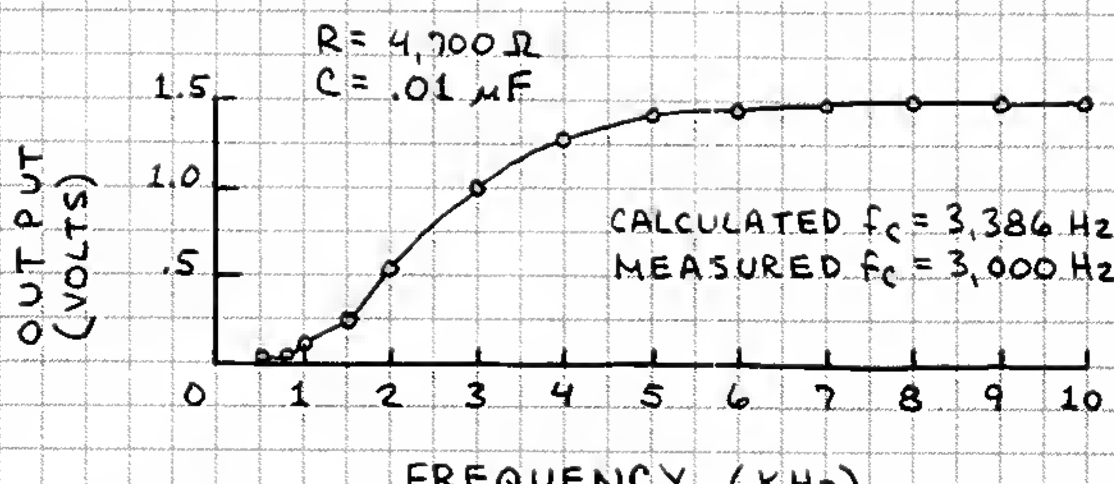
R1 = R2 = R
C1 = C2 = C

CUTOFF FREQUENCY IS .707 TIMES MAXIMUM OUTPUT.

$$f_c = \frac{1}{2\pi RC}$$

GAIN = R4/R3 (ABOUT 1.59)

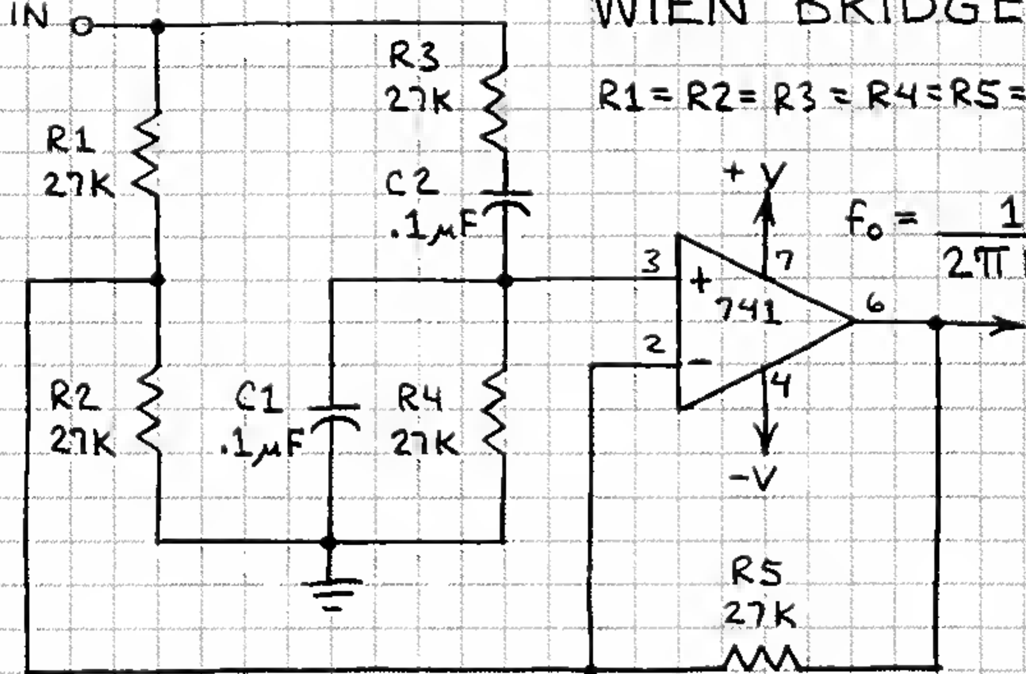
THIS CIRCUIT IS IDENTICAL TO THE EQUAL COMPONENT SALLEN-KEY FILTER ON FACING PAGE EXCEPT R1 AND R2 AND C1 AND C2 HAVE BEEN INTERCHANGED. BELOW IS RESPONSE WHEN INPUT WAS A 1-VOLT SINE WAVE:



60-HZ NOTCH FILTER

WIEN BRIDGE

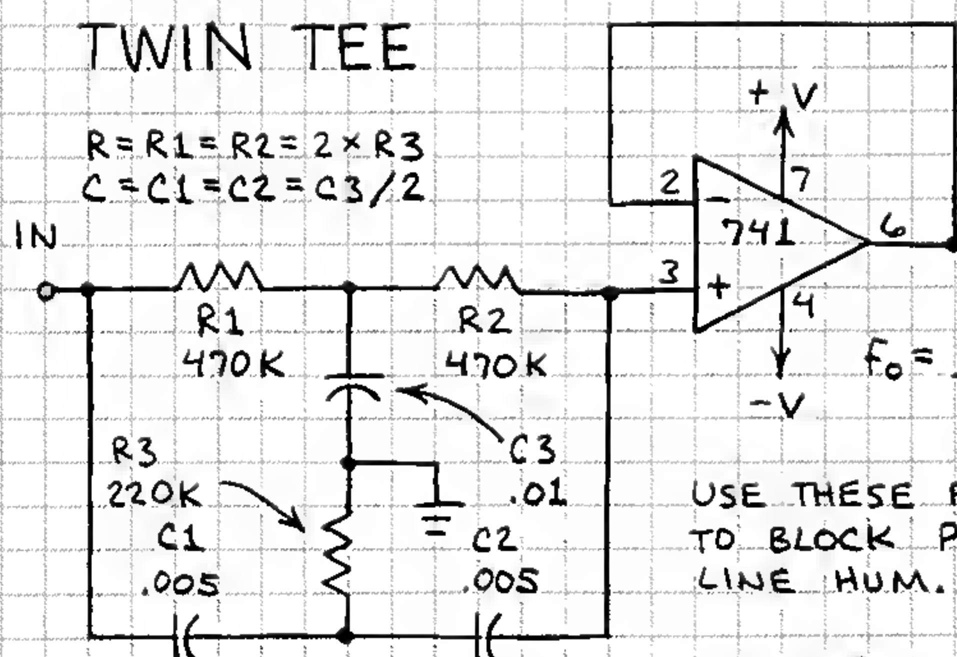
R1 = R2 = R3 = R4 = R5 = 27K



$$f_o = \frac{1}{2\pi RC}$$

TWIN TEE

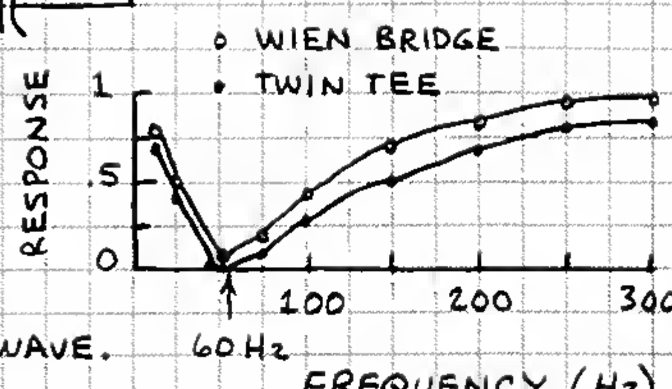
R = R1 = R2 = 2 × R3
C = C1 = C2 = C3/2



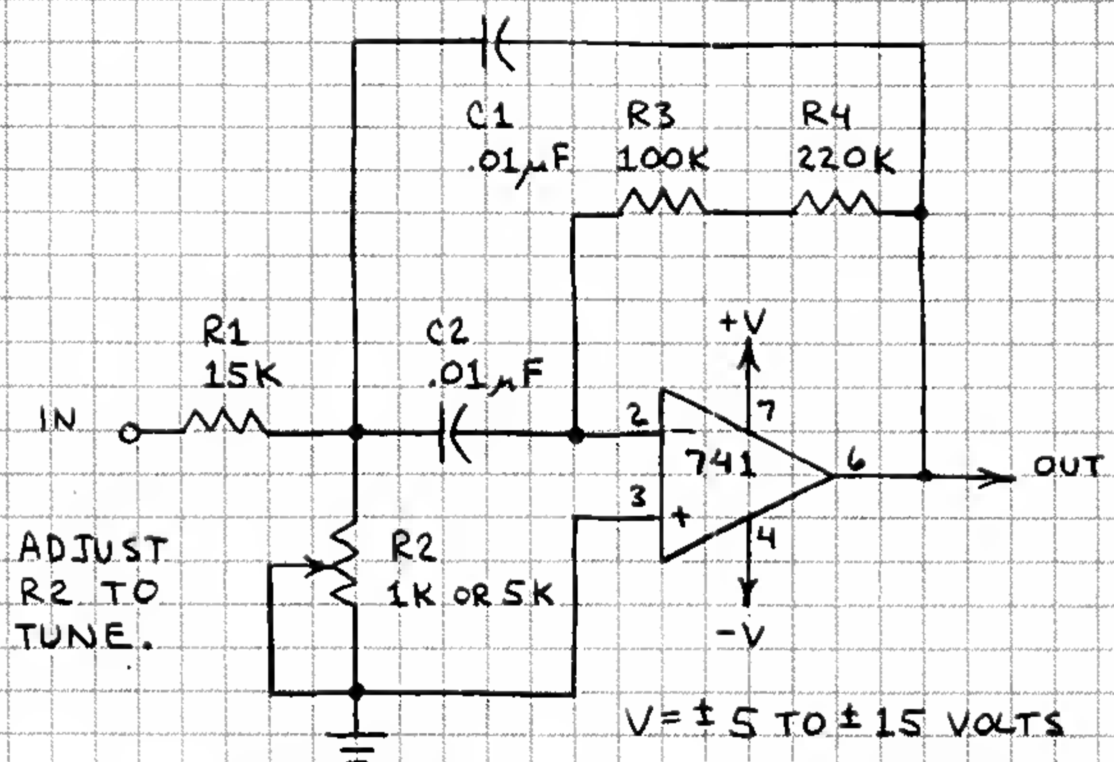
$$f_o = \frac{1}{2\pi RC}$$

USE THESE FILTERS TO BLOCK POWER LINE HUM.

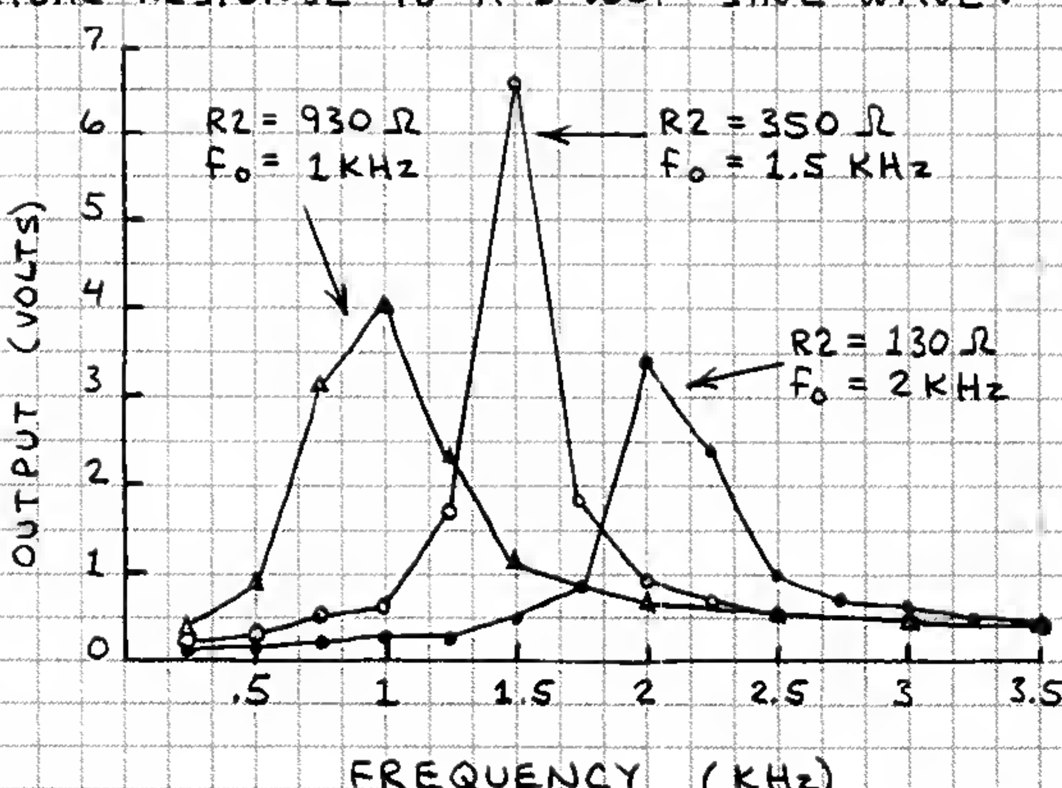
GRAPH SHOWS RESULTS FOR TEST VERSIONS OF BOTH FILTERS. INPUT WAS 1-VOLT PEAK-TO-PEAK SINE WAVE.



TUNABLE BANDPASS FILTER

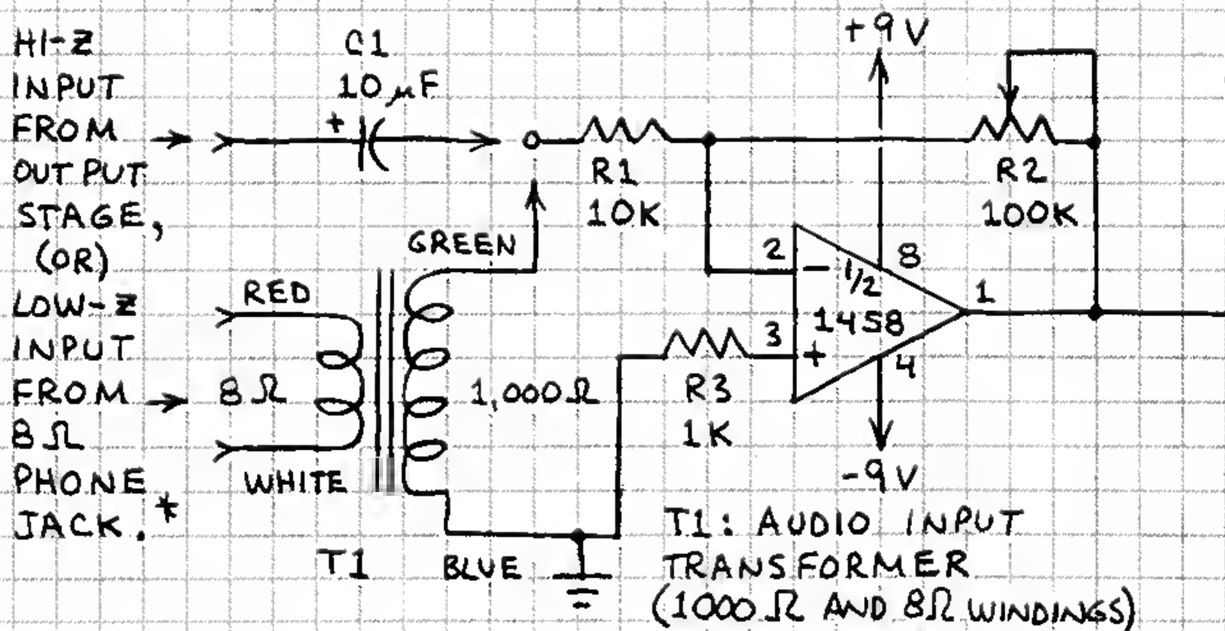


THIS FILTER CAN BE TUNED BY R2 TO PASS A NARROW FREQUENCY BAND BETWEEN A FEW HUNDRED Hz AND ABOUT 3,000 Hz. USE TO DETECT PRESENCE OF A TONE IN A SIGNAL. ACTUAL RESPONSE TO A 1-VOLT SINE WAVE:



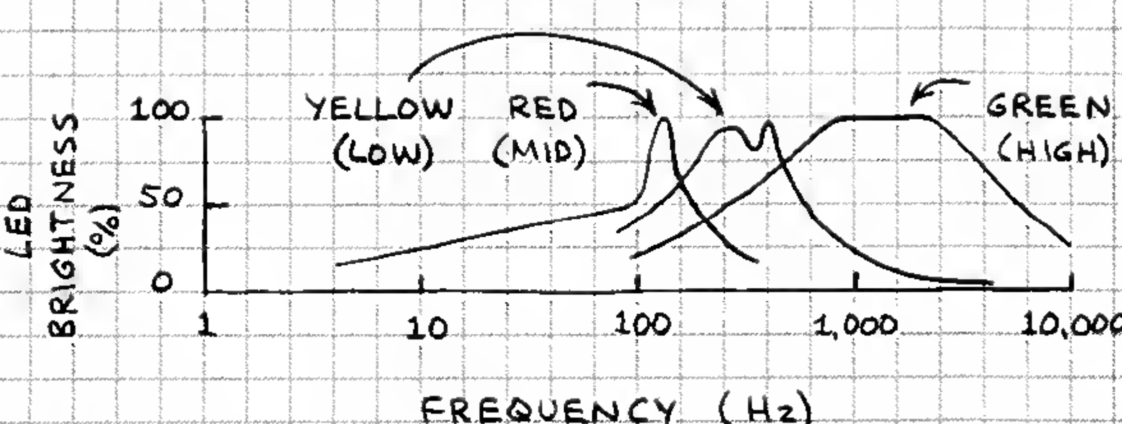
MINI-COLOR ORGAN

THIS ARRAY OF ACTIVE FILTERS WILL CONVERT THE AUDIO SIGNAL FROM A SMALL RADIO OR TAPE PLAYER INTO A FLICKERING PATTERN OF COLORS. R2 CONTROLS GAIN OF THE INPUT AMPLIFIER BELOW. USE RADIO/TAPE PLAYER VOLUME CONTROL AND R2 TO ADJUST INTENSITY OF LEDs.



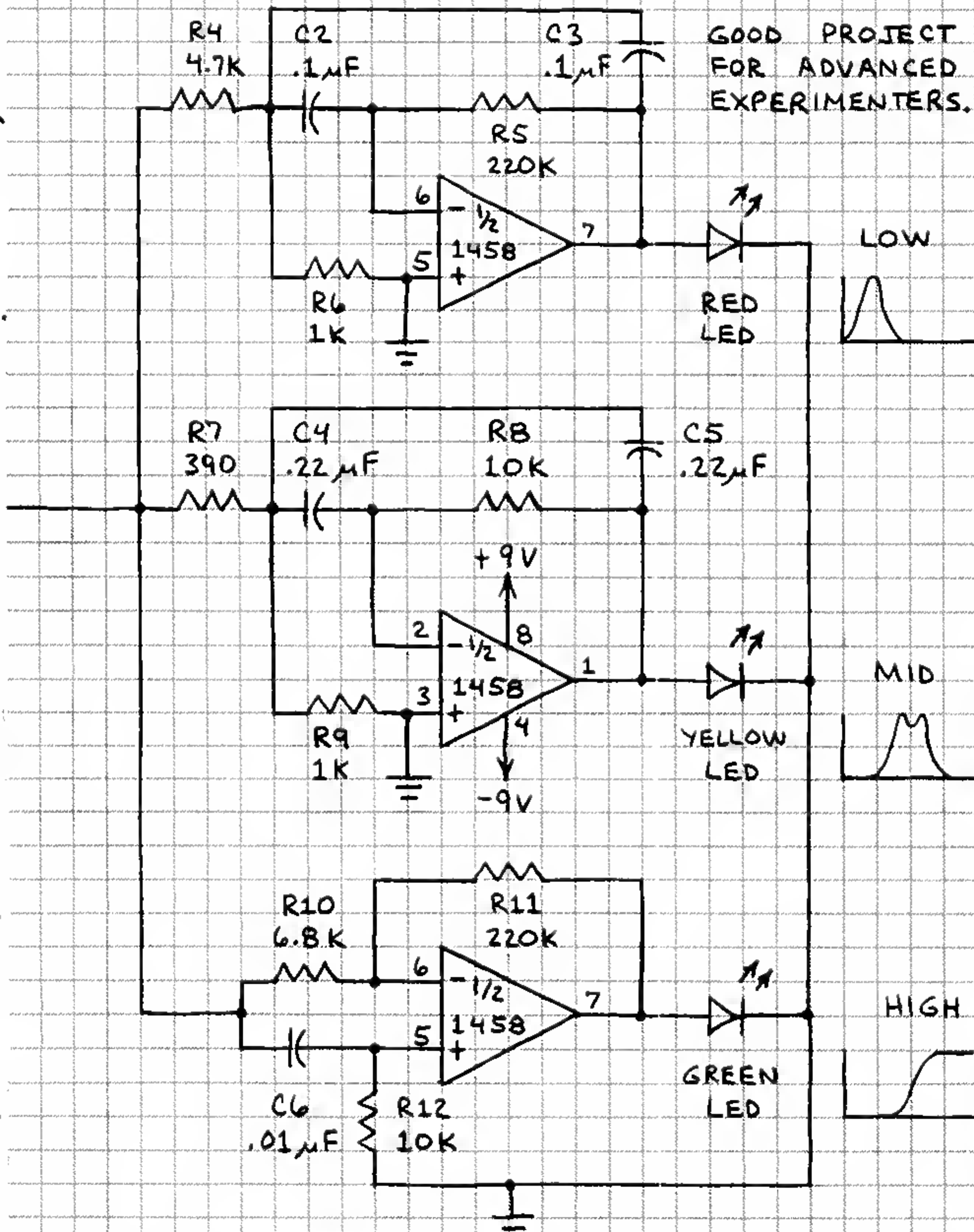
*INSERT PHONE PLUG CONNECTED TO T1 PART WAY IN PHONE JACK SO SPEAKER WILL NOT BE SWITCHED OFF.

LEDs VARY IN BRIGHTNESS. EXPERIMENT WITH DIFFERENT LEDs FOR BEST RESULTS. HERE IS ACTUAL RESPONSE OF CIRCUIT:



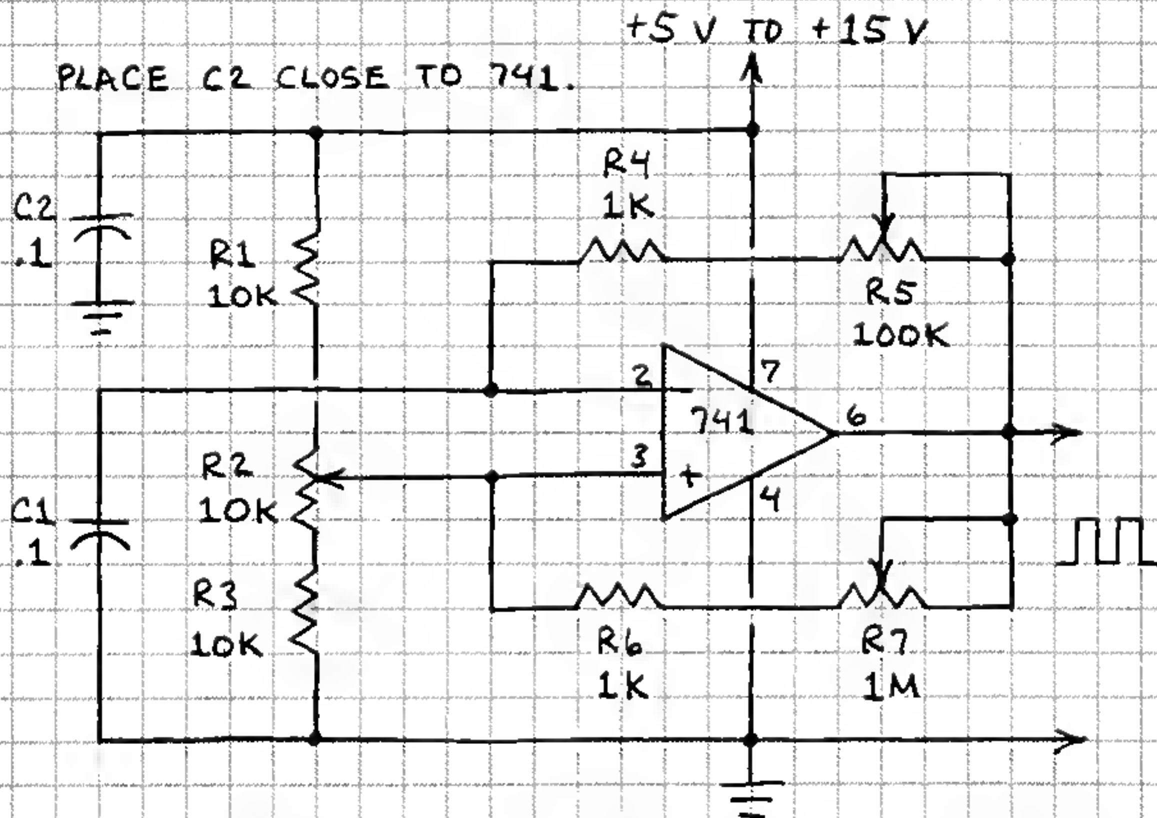
MINI-COLOR ORGAN (CONT.)

GOOD PROJECT FOR ADVANCED EXPERIMENTERS.



REDUCE R4 AND R7 TO INCREASE RED AND YELLOW BRIGHTNESS. INCREASE R11 TO INCREASE GREEN BRIGHTNESS.

SQUARE WAVE GENERATOR



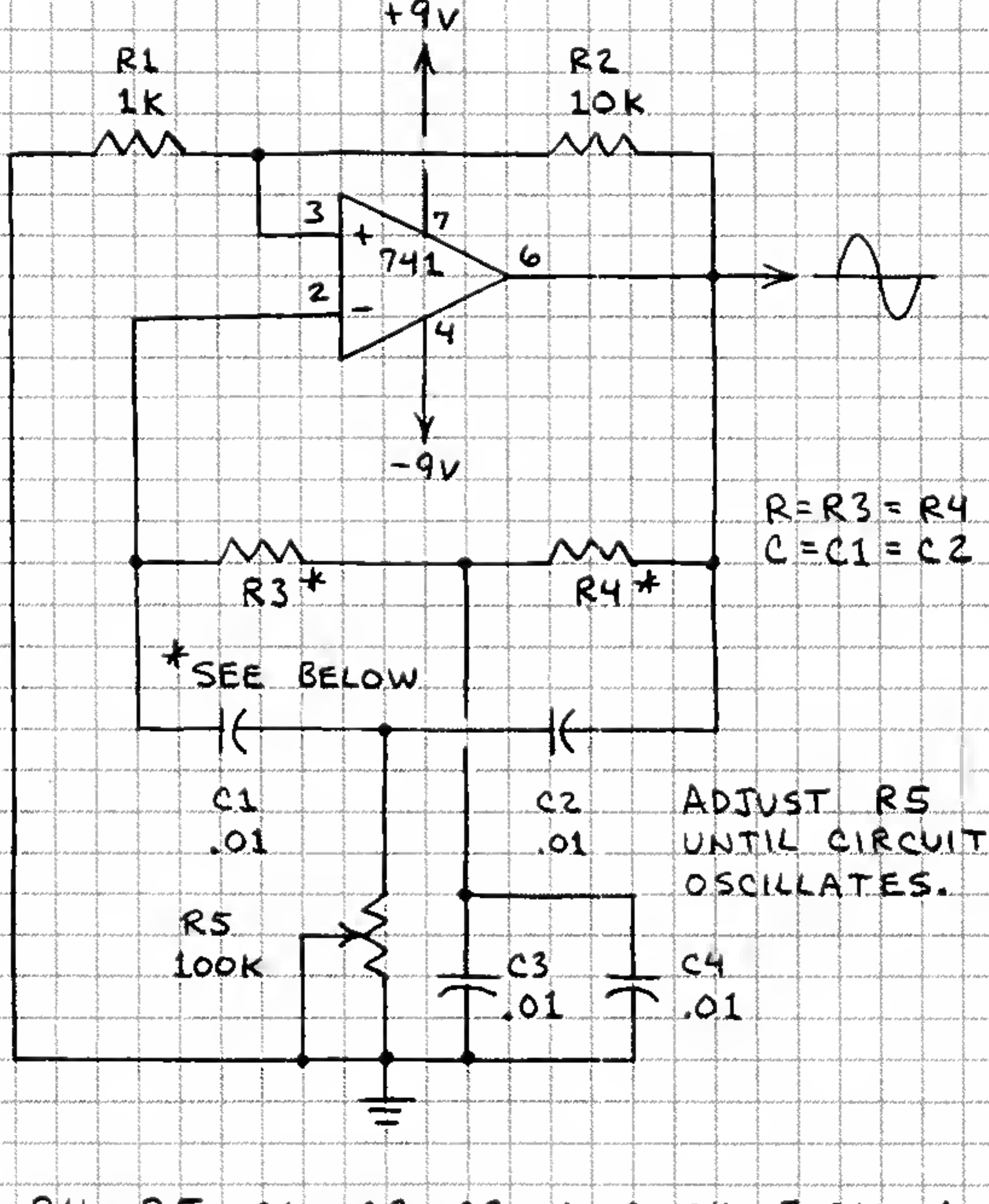
THIS CIRCUIT IS AN EASILY ADJUSTABLE SQUARE WAVE GENERATOR. THE TIMING COMPONENTS ARE C1, R4, R5, R6 AND R7. R1-R2-R3 CONTROL THE DURATION (OR "WIDTH") OF THE PULSES. THE PULSES ARE SYMMETRICAL WHEN R2 IS AT ITS CENTER POSITION. OK TO CONNECT R2 DIRECTLY TO +V AND ⏚, THEREBY ELIMINATING R1 AND R3. TYPICAL RESULTS:

C1	FREQUENCY
.001	11,480 Hz
.047	3,848 Hz
.01	2,155 Hz
.047	462 Hz
.1	227 Hz
.47	45 Hz
1.0	24 Hz

FOR THESE RESULTS, R1-R2-R3 REPLACED BY 4.7K FROM PIN 3 TO +V AND 4.7K FROM PIN 3 TO GROUND. R4+R5 = 100K, R6+R7 = 22K, AND +V = +12 VOLTS.

OK TO ADD FOLLOWER STAGE TO BUFFER OUTPUT.

SINE WAVE OSCILLATOR

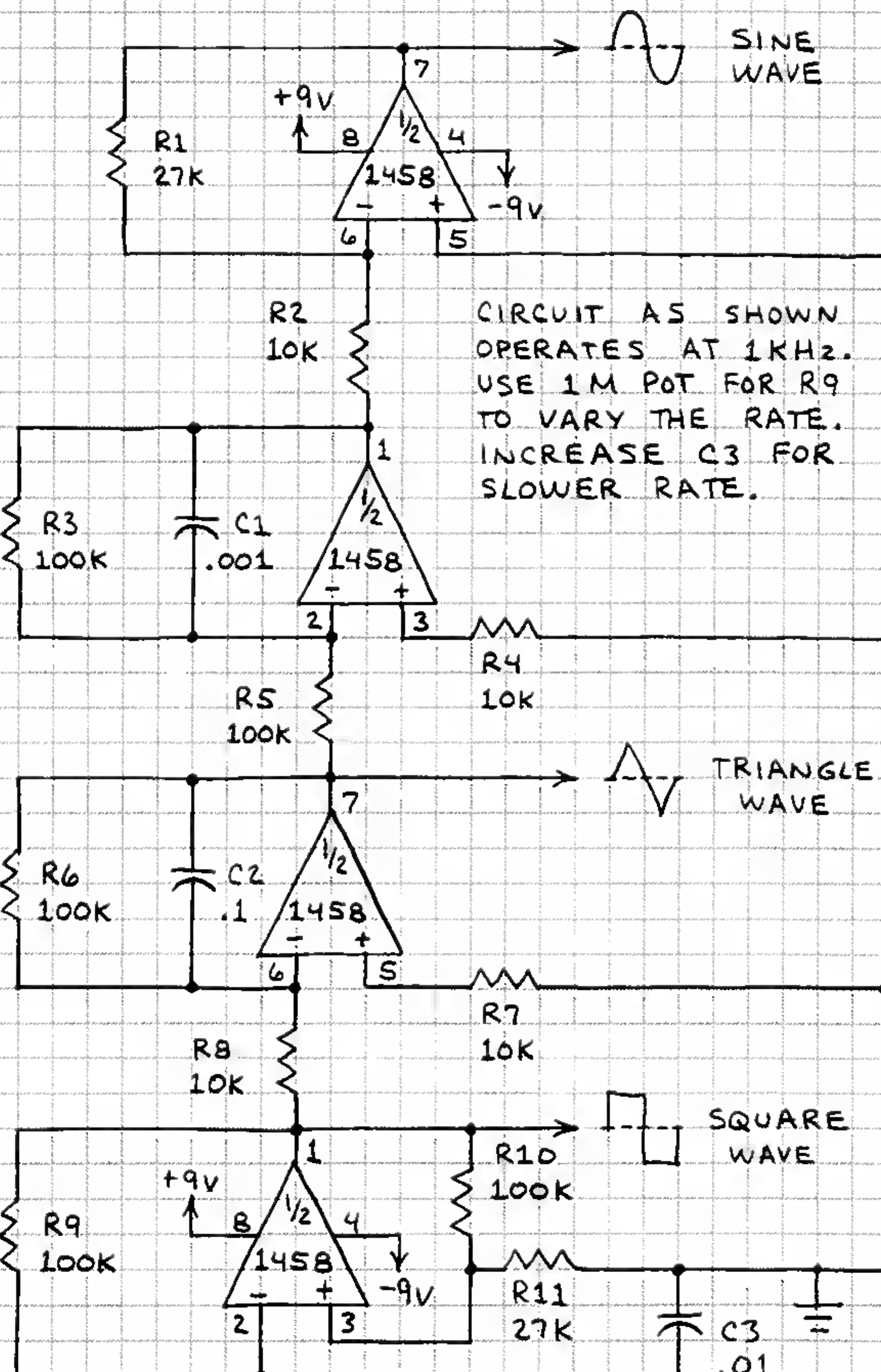


R3, R4, R5, C1, C2, C3, AND C4 FORM A TWIN-TEE FILTER. WHEN CONNECTED IN THE FEEDBACK LOOP OF AN OP-AMP, THE RESULTING CIRCUIT GENERATES A SINE WAVE. THE FREQUENCY IS $1/(2\pi RC)$.

TYPICAL RESULTS FROM TEST CIRCUIT:

R3 = R4	FREQUENCY
4.7 K	2926 Hz
10 K	1356 Hz
15 K	927 Hz

FUNCTION GENERATOR



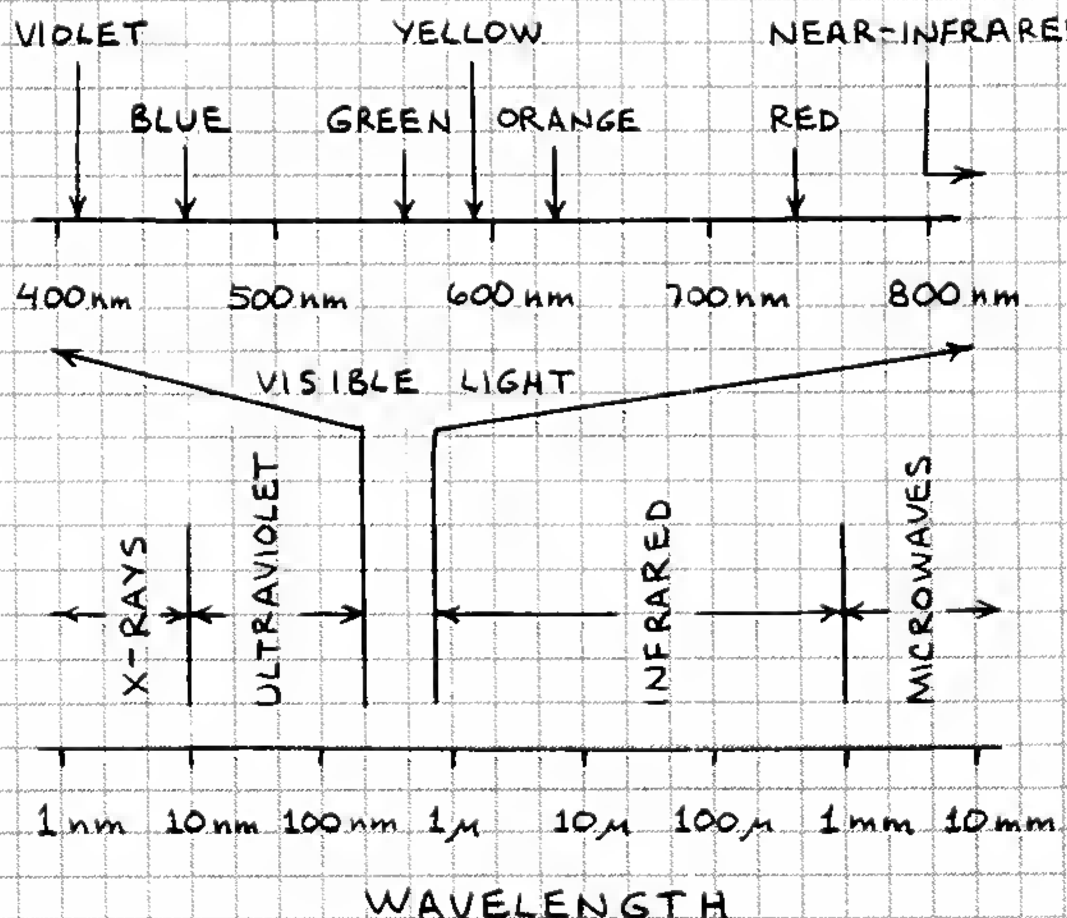
III. OPTOELECTRONICS

OVERVIEW

PARTS THAT EMIT OR DETECT LIGHT ARE OPTOELECTRONIC COMPONENTS. OPTOELECTRONIC CIRCUITS HAVE WIDESPREAD APPLICATIONS IN COMMUNICATIONS, SENSING, CONTROL, AND READOUTS. MANY KINDS OF SOLID-STATE OPTOELECTRONIC COMPONENTS ARE AVAILABLE AT REASONABLE PRICES FROM RADIO SHACK. SO IS "GETTING STARTED IN ELECTRONICS," A BOOK THAT WILL HELP YOU ASSEMBLE THE CIRCUITS IN THIS BOOK.

THE OPTICAL SPECTRUM

nm = NANOMETER (1 nm = .000 000 001 METER)
μ = MICROMETER (1 μ = .000 001 METER)
mm = MILLIMETER (1 mm = .001 METER)



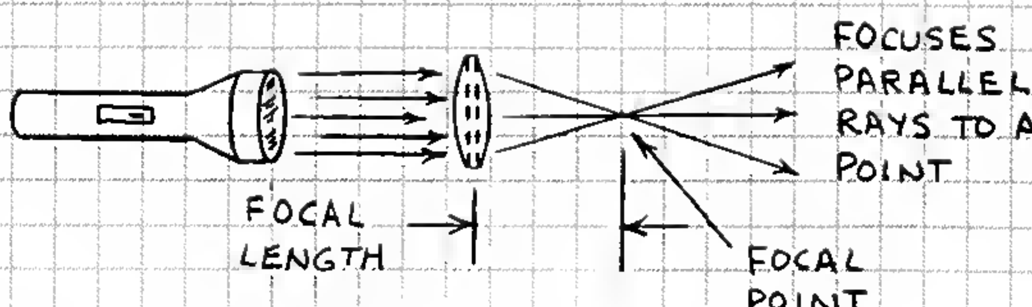
OPTICAL COMPONENTS

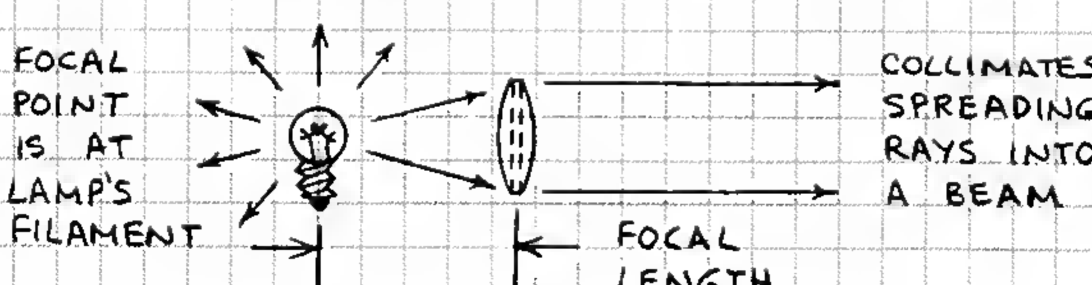
OPTICAL COMPONENTS CONDUCT, BEND, OR CHANGE THE CHARACTERISTICS OF LIGHT. MANY OPTICAL COMPONENTS CAN BE FOUND AROUND THE HOME OR OFFICE. OTHERS MUST BE PURCHASED FROM SCIENCE SUPPLY COMPANIES.

SIMPLE LENSES

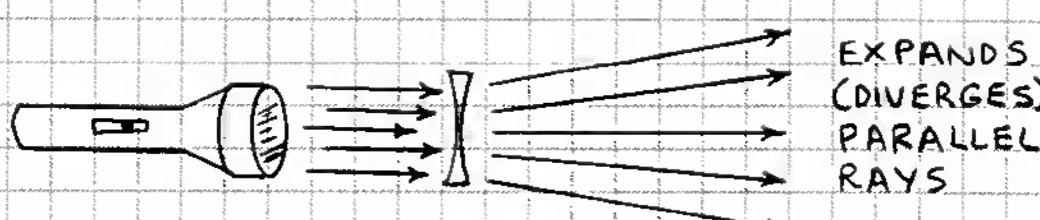
LENSES MADE OF GLASS OR PLASTIC ARE AMONG THE MOST IMPORTANT OPTICAL COMPONENTS.

POSITIVE (CONVEX) LENS

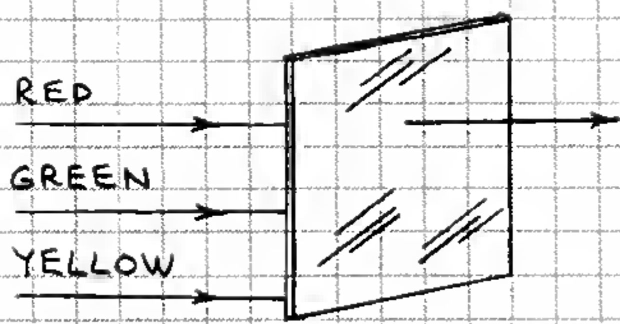




NEGATIVE (CONCAVE) LENS

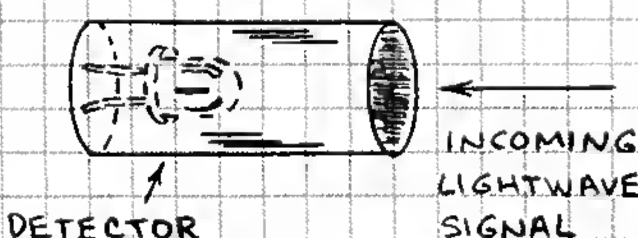


FILTERS



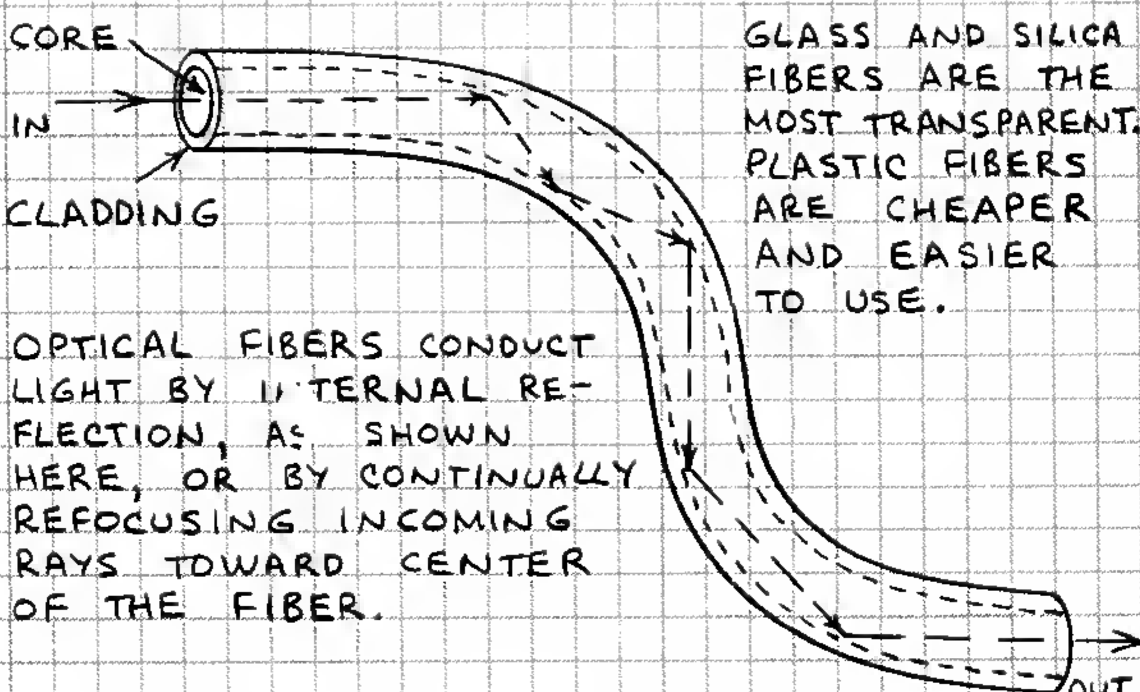
FILTERS TRANSMIT A NARROW BAND OF OPTICAL WAVELENGTHS. USE COLORED CELLOPHANE FOR VISIBLE LIGHT OR DEVELOPED COLOR FILM FOR INFRARED.

LIGHT SHIELDS



TUBE LINED WITH BLACK PAPER OR COATED WITH FLAT BLACK PAINT KEEPS EXTERNAL LIGHT AWAY FROM DETECTOR.

OPTICAL FIBERS



GLASS AND SILICA FIBERS ARE THE MOST TRANSPARENT. PLASTIC FIBERS ARE CHEAPER AND EASIER TO USE.

OPTICAL FIBERS CONDUCT LIGHT BY INTERNAL RE-FLECTION, AS SHOWN HERE, OR BY CONTINUALLY REFOCUSING INCOMING RAYS TOWARD CENTER OF THE FIBER.

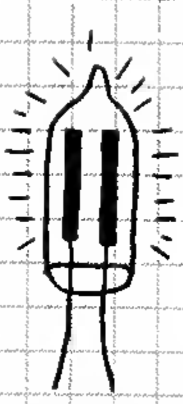
LIGHT SOURCES

MANY LIGHT SOURCES ARE AVAILABLE FOR OPTOELECTRONIC PROJECTS. THE MOST IMPORTANT SOURCES INCLUDE:

INCANDESCENT LAMPS

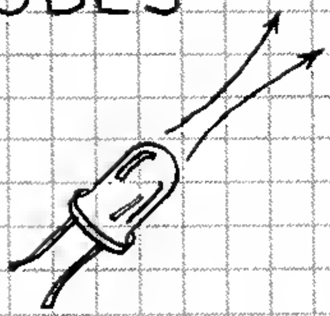
AN INCANDESCENT LAMP IS MADE BY ENCLOSING A THIN TUNGSTEN WIRE (THE FILAMENT) IN AN EVACUATED GLASS ENVELOPE. AN ELECTRICAL CURRENT PASSED THROUGH THE FILAMENT CAUSES IT TO BECOME INCANDESCENT (WHITE HOT). THE OPERATING LIFE AND BRILLIANCE OF AN INCANDESCENT LAMP CAN BE INCREASED BY FILLING THE ENVELOPE WITH A GAS SUCH AS ARGON, NITROGEN, OR KRYPTON. THE ULTRA-BRIGHT HALOGEN LAMP HAS A QUARTZ ENVELOPE FILLED WITH A HALOGEN GAS LIKE IODINE OR BROMINE. THE GAS COMBINES WITH TUNGSTEN ON THE ENVELOPE WALL AND DEPOSITS IT ON THE FILAMENT.

GAS-DISCHARGE LAMPS



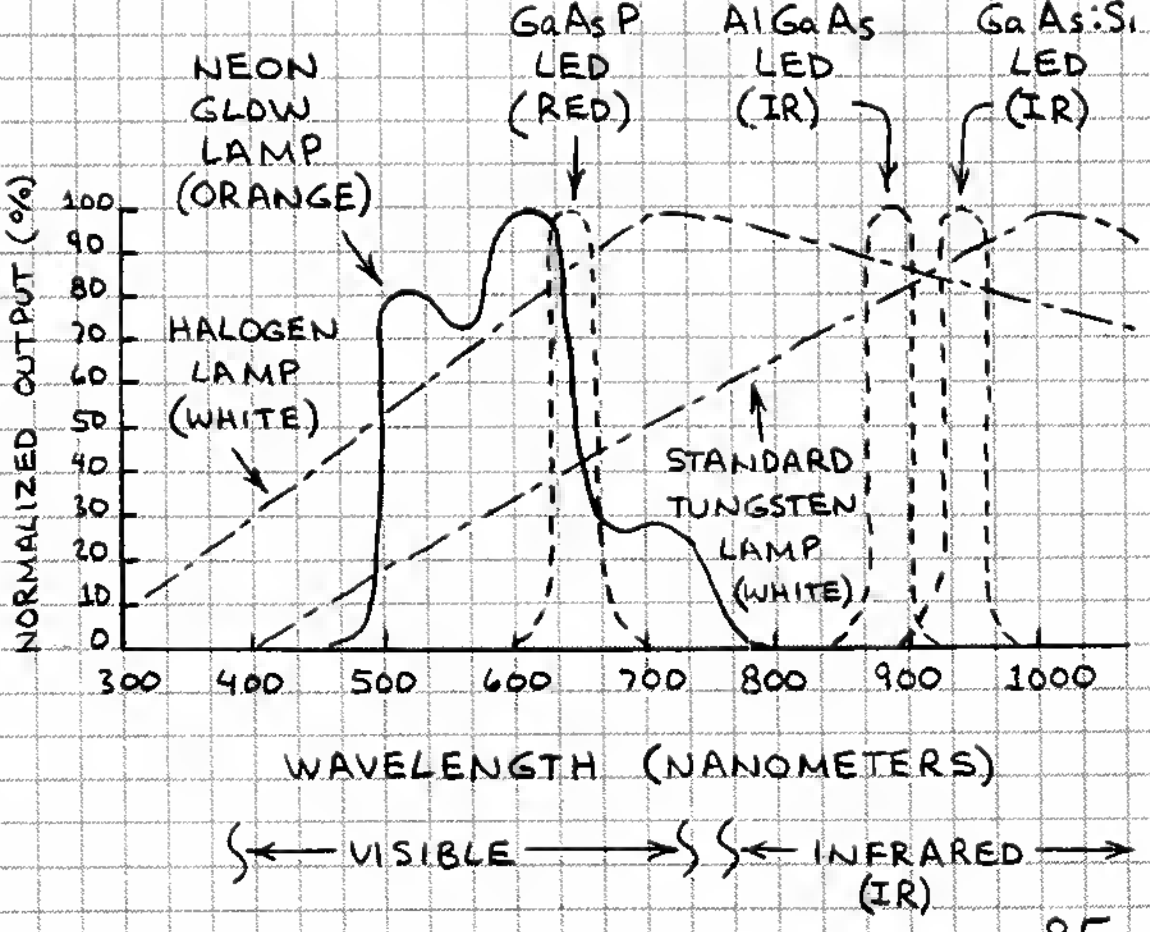
THE SIMPLEST GAS-DISCHARGE LAMP, THE NEON GLOW LAMP, IS A GLASS ENVELOPE FILLED WITH NEON GAS. WHEN THE VOLTAGE ACROSS TWO ELECTRODES IN THE ENVELOPE EXCEEDS 60-70 VOLTS, THE IONIZATION OR BREAKDOWN VOLTAGE OF NEON, AN ELECTRICAL DISCHARGE IS ESTABLISHED BETWEEN THE ELECTRODES, AND THE NEON EMITS AN ORANGE GLOW. OTHER GAS-DISCHARGE LAMPS ARE THE XENON FLASH LAMP AND THE MERCURY VAPOR LAMP.

LIGHT-EMITTING DIODES



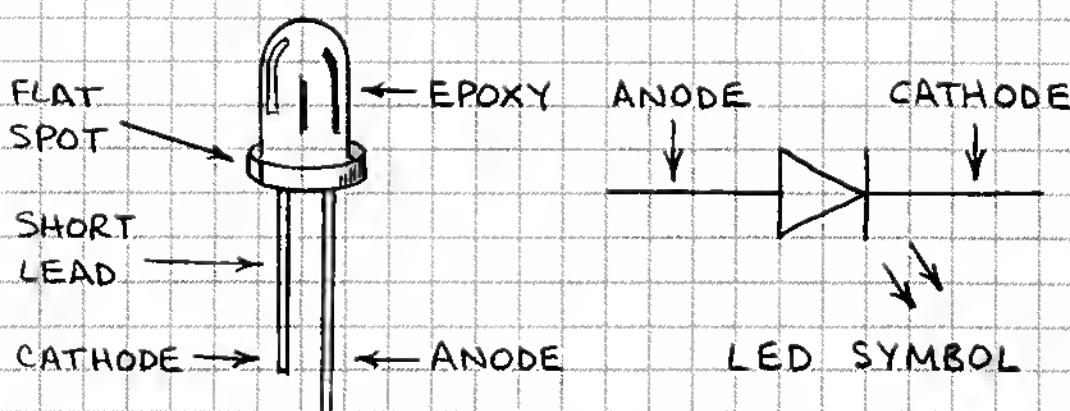
THE LIGHT-EMITTING DIODE (LED) IS A SEMICONDUCTOR PN JUNCTION DIODE THAT EMITS VISIBLE LIGHT OR NEAR-INFRARED RADIATION WHEN FORWARD BIASED. VISIBLE LEDs EMIT RELATIVELY NARROW BANDS OF GREEN, YELLOW, ORANGE, OR RED LIGHT. INFRARED DIODES EMIT IN ONE OF SEVERAL BANDS JUST BEYOND RED LIGHT. LEDs SWITCH OFF AND ON RAPIDLY, ARE VERY EFFICIENT, HAVE A VERY LONG LIFETIME, AND ARE EASY TO USE. LEDs ARE CURRENT DEPENDENT SOURCES, AND THEIR LIGHT OUTPUT IS DIRECTLY PROPORTIONAL TO THE FORWARD CURRENT.

LIGHT SOURCE SPECTRA

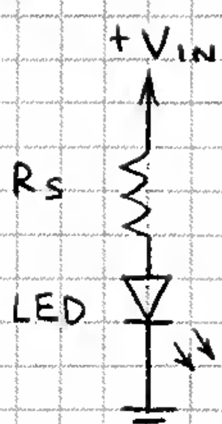


HOW TO USE LEDs

LIGHT-EMITTING DIODES ARE VERY RUGGED, LONG-LIVED OPTICAL SOURCES. THE LIGHT THEY EMIT HAS AN INTENSITY THAT IS LINEAR WITH RESPECT TO THE FORWARD CURRENT THROUGH THE LED. TO PREVENT IRREVERSIBLE DAMAGE, ALWAYS OPERATE AN LED WITHIN ITS RATINGS.



USE A SERIES RESISTOR (R_S) TO LIMIT THE CURRENT THROUGH AN LED TO A SAFE VALUE.



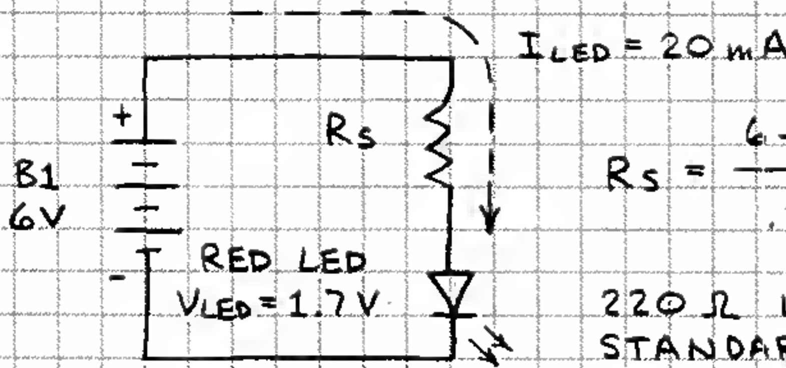
USE THIS FORMULA TO DETERMINE THE RESISTANCE OF R_S:

$$R_S = \frac{V_{IN} - V_{LED}}{I_{LED}}$$

I_{LED} IS THE SPECIFIED FORWARD CURRENT.

V_{LED} IS THE LED VOLTAGE DROP. IT RANGES FROM ABOUT 1.3 VOLTS (940 nm INFRARED EMITTERS) TO ABOUT 2.5 VOLTS (GREEN EMITTERS).

SAMPLE LED CIRCUIT

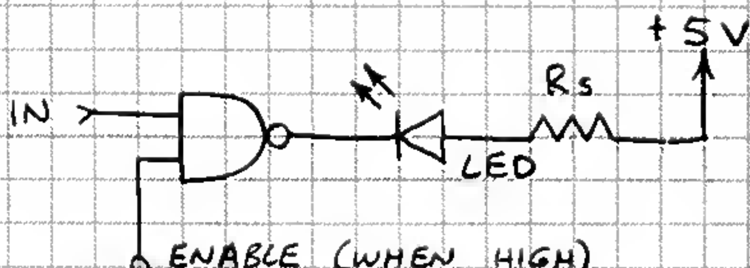


$$R_S = \frac{6 - 1.7}{.02} = 215 \text{ OHMS}$$

220 Ω IS CLOSEST STANDARD VALUE.

LOGIC CIRCUIT LED DRIVERS

TTL:

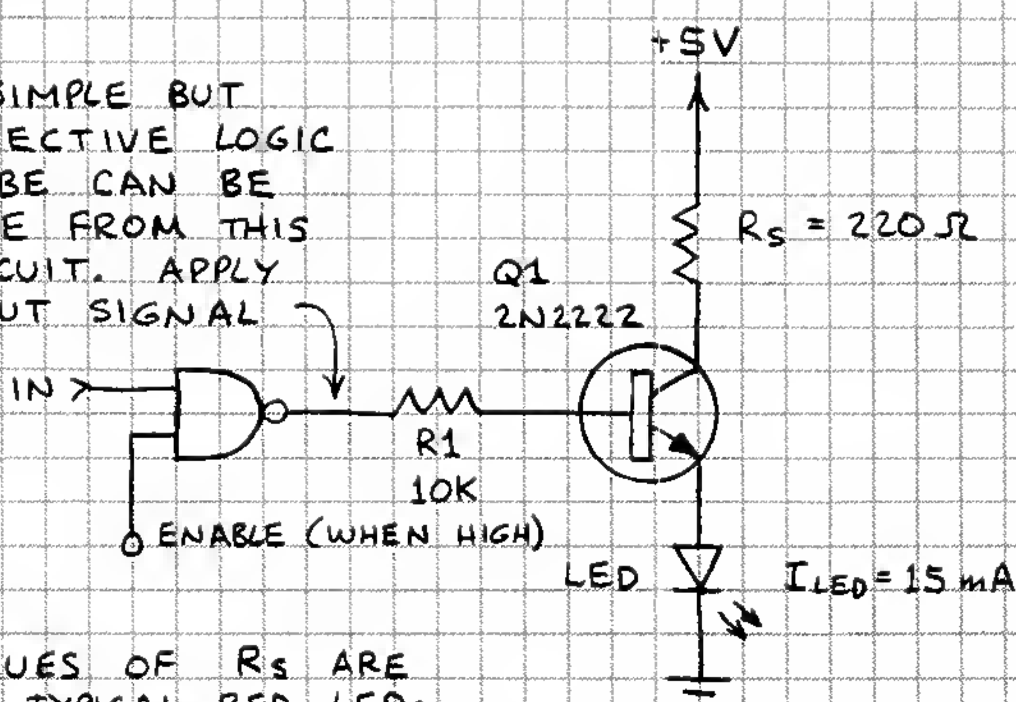


$R_S = 220\,\Omega$

$I_{LED} = 15\ mA$

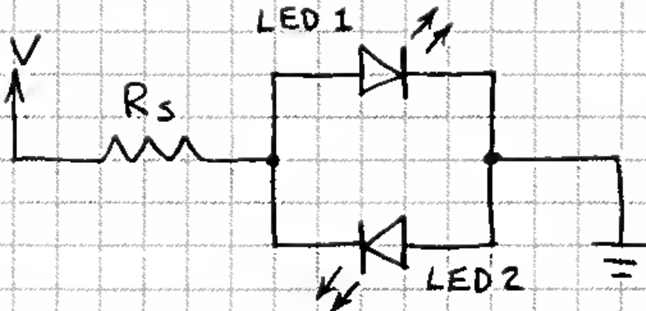
TTL OR CMOS:

A SIMPLE BUT EFFECTIVE LOGIC PROBE CAN BE MADE FROM THIS CIRCUIT. APPLY INPUT SIGNAL



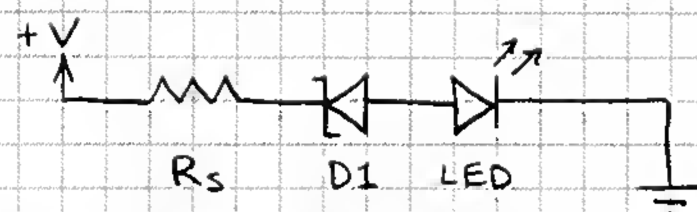
VALUES OF R_S ARE FOR TYPICAL RED LEDs.

AC/DC POLARITY INDICATOR



V	LED 1	LED 2
+	ON	OFF
–	OFF	ON
AC	ON	ON

VOLTAGE-LEVEL INDICATOR



D1 IS A ZENER DIODE.

LED WILL GLOW WHEN +V EXCEEDS THE BREAKDOWN VOLTAGE OF THE ZENER DIODE. NOTE THAT D1 IS REVERSE BIASED.

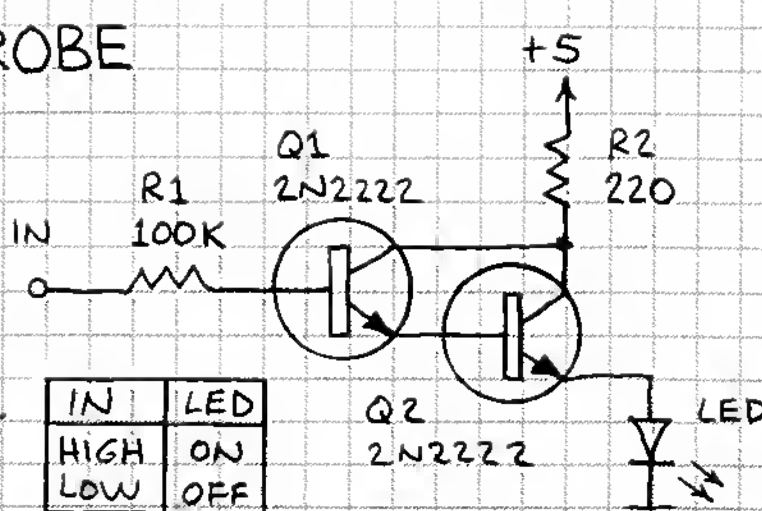
LED BRIGHTNESS CONTROL

SELECT Rs AS IF R1 NOT PRESENT.

1K (ADJUST TO ALTER LED BRIGHTNESS.)

LOGIC PROBE

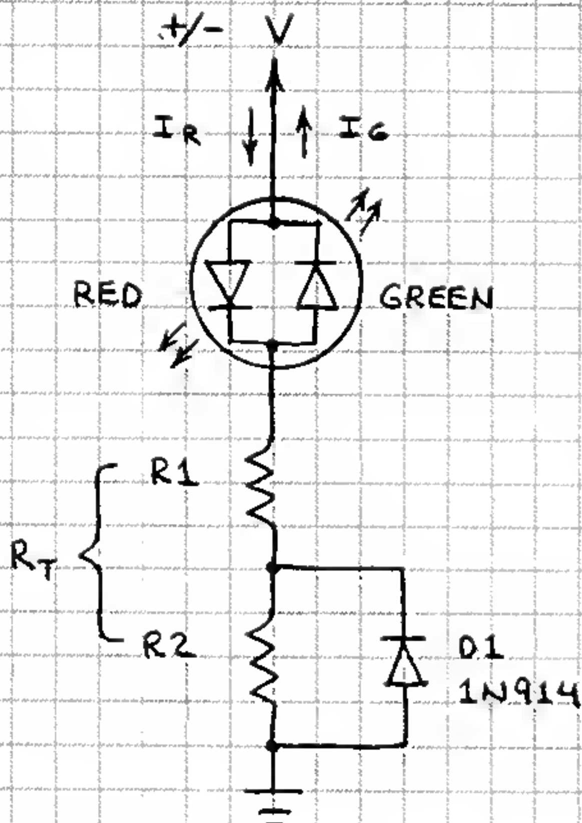
USE THIS PROBE TO MONITOR THE LOGICAL STATUS OF LOGIC GATES.



IN	LED
HIGH	ON
LOW	OFF

HOW TO USE TRI-COLOR LEDs

TRI-COLOR LEDs ARE MADE BY INSTALLING A RED AND GREEN LED CHIP IN THE SAME PACKAGE. THE TWO CHIPS ARE USUALLY CONNECTED IN REVERSE-PARALLEL.



$R_T = R1 + R2$

I_R = RED LED CURRENT

I_G = GREEN LED CURRENT

V	COLOR
+	RED
−	GREEN
AC	YELLOW

$$R_T = \frac{+/- V - V_R}{I_R}$$

$$R1 = \frac{+/- V - (V_G + V_D)}{I_G}$$

V_R = RED LED FORWARD VOLTAGE (ABOUT 2 V)

V_G = GREEN LED FORWARD VOLTAGE (ABOUT 2 V)

V_D = D1 FORWARD VOLTAGE (0.6 V).

SAMPLE CALCULATION:

ASSUME +/- V = 5 VOLTS AND I_R & I_G = 20 MILLIAMPERES.

$$R_T = \frac{5-2}{.02} = 150 \text{ OHMS} \qquad R1 = \frac{5-(2+.6)}{.02} = 120 \text{ OHMS}$$

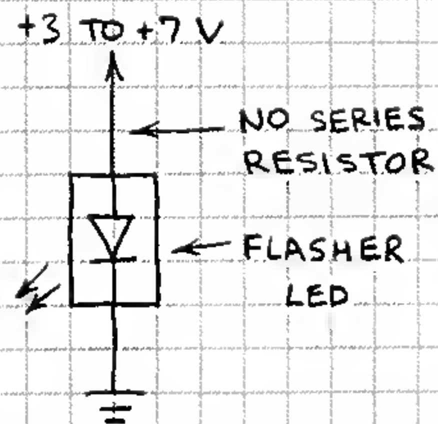
$R2 = R_T - R1 = 30$ OHMS

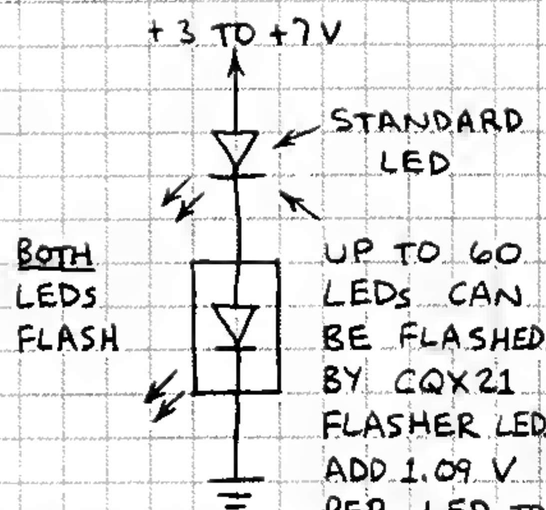
SELECT STANDARD RESISTANCE VALUES CLOSEST TO THESE.

HOW TO USE FLASHER LEDs

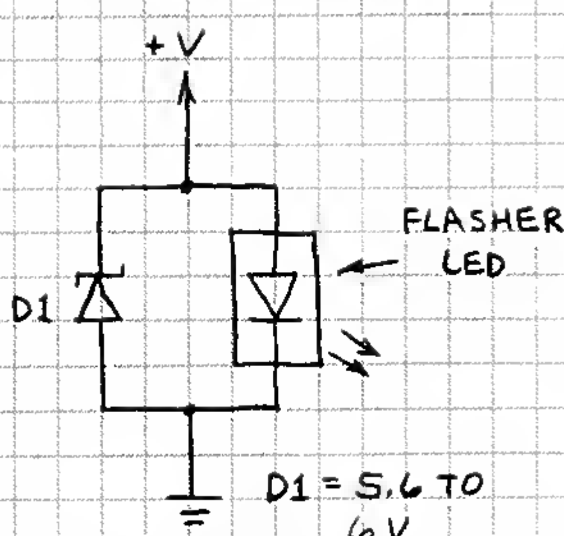
FLASHER LEDs INCLUDE IN THE LED PACKAGE A MINIATURE INTEGRATED CIRCUIT THAT CAUSES THE LED TO FLASH FROM 2 TO 6 TIMES EACH SECOND. CAN BE USED WITHOUT A SERIES RESISTOR.

BASIC LED FLASHERS

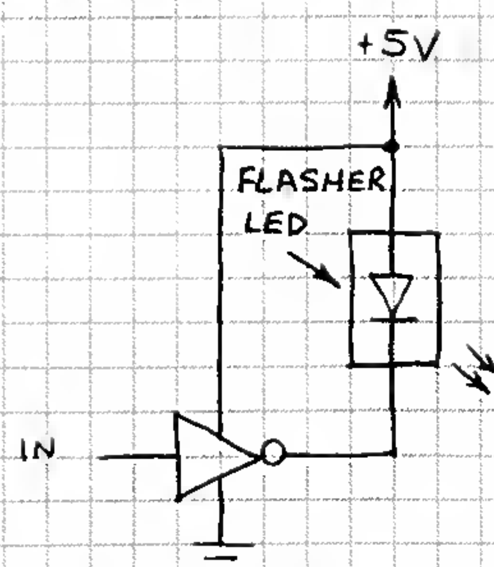




FLASH RATE DECREASES AS FORWARD VOLTAGE INCREASES.

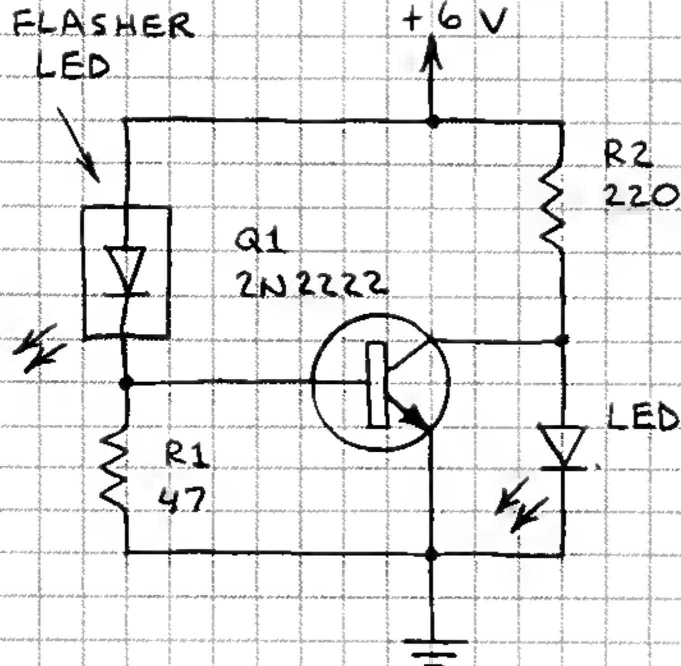


USE THIS CIRCUIT WHEN VOLTAGE EXCEEDS SAFE VALUE. D1 IS A ZENER DIODE.



HOW TO DRIVE FLASHER LED FROM A TTL GATE. THIS WILL WORK WITH HIGH-OUTPUT CMOS.

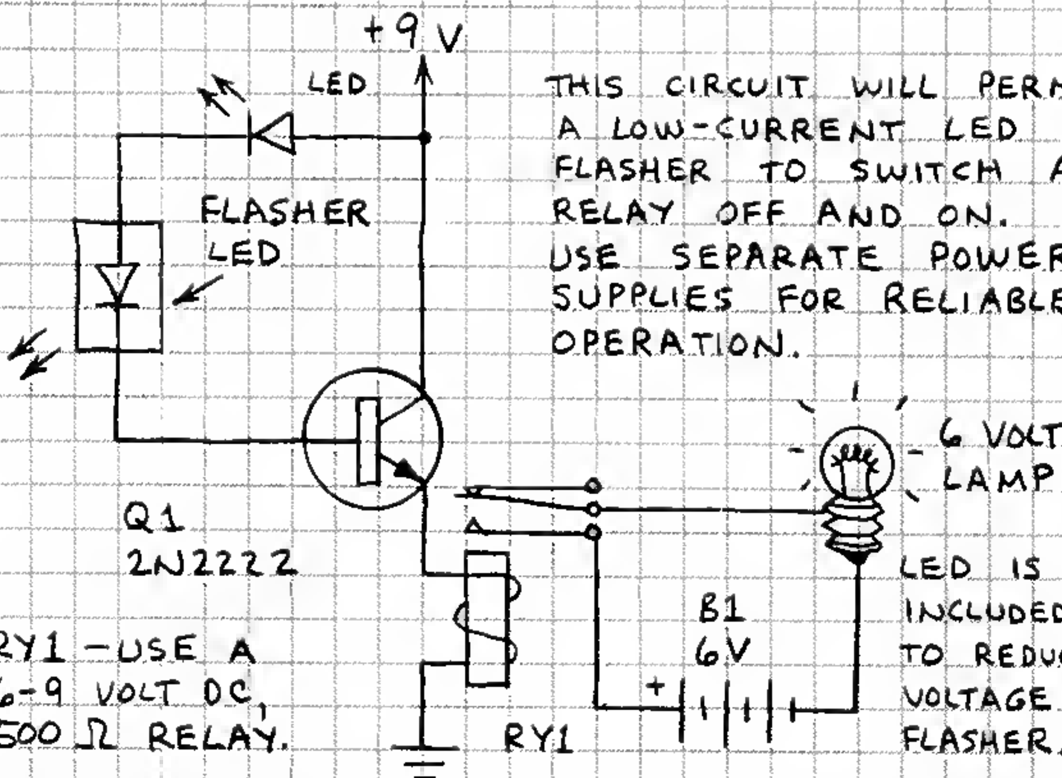
DUAL LED FLASHER



WHEN THE SUPPLY VOLTAGE IS 6 VOLTS, THE LEDs WILL FLASH ALTERNATELY. THE STANDARD LED WILL REMAIN ON WHEN THE SUPPLY VOLTAGE FALLS BELOW 6 VOLTS.

POWER FLASHER

THIS CIRCUIT WILL PERMIT A LOW-CURRENT LED FLASHER TO SWITCH A RELAY OFF AND ON. USE SEPARATE POWER SUPPLIES FOR RELIABLE OPERATION.

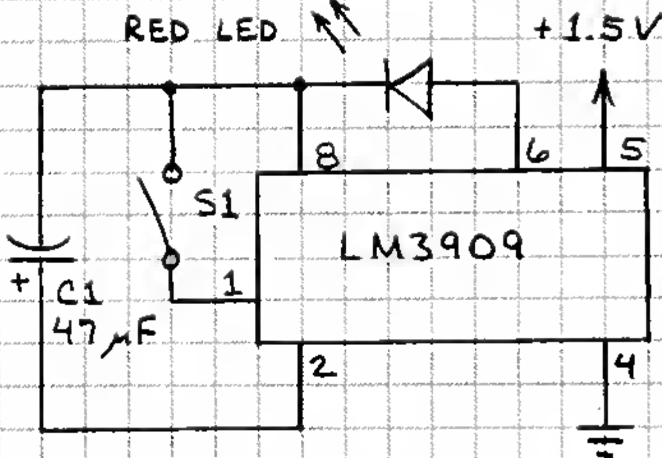


LED IS INCLUDED TO REDUCE VOLTAGE TO FLASHER.

RY1 — USE A 6-9 VOLT DC, 500 Ω RELAY.

CAUTION: DO NOT USE THIS CIRCUIT TO FLASH LINE-POWERED LAMPS. DO NOT EXCEED THE CURRENT RATING OF THE RELAY'S CONTACTS.

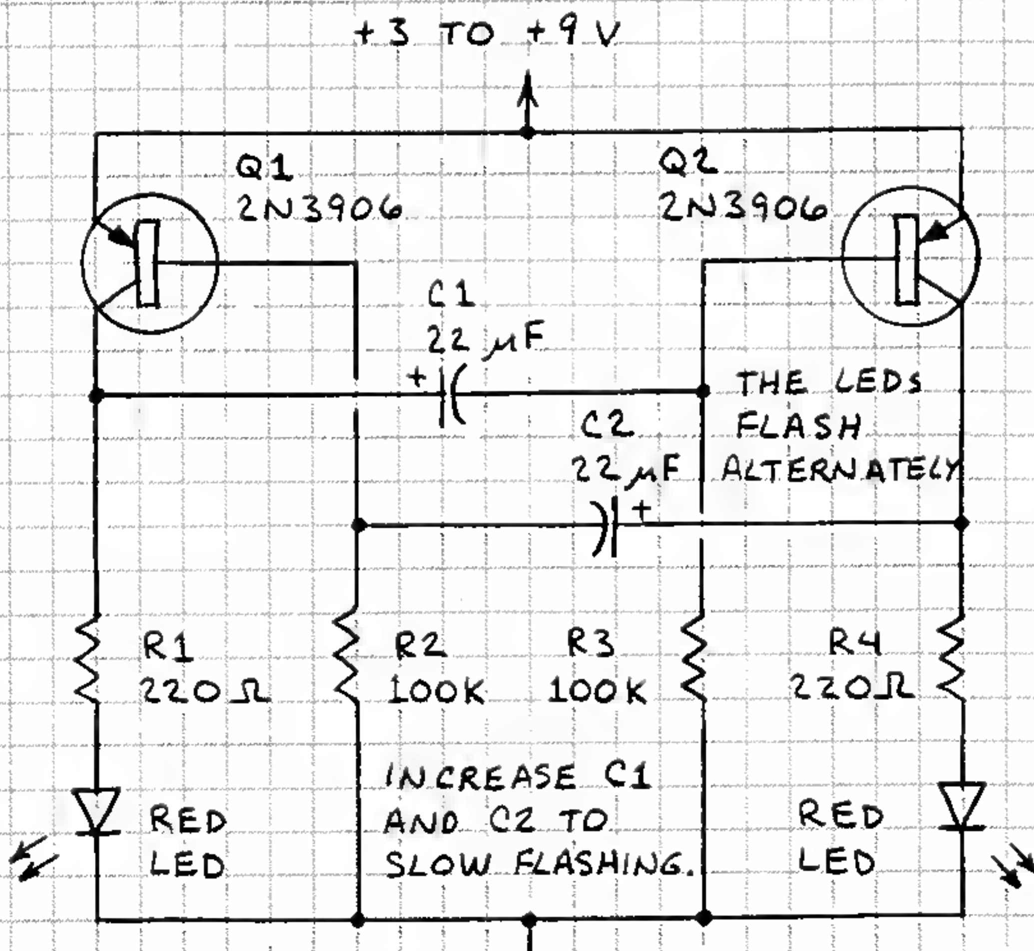
SINGLE LED FLASHER



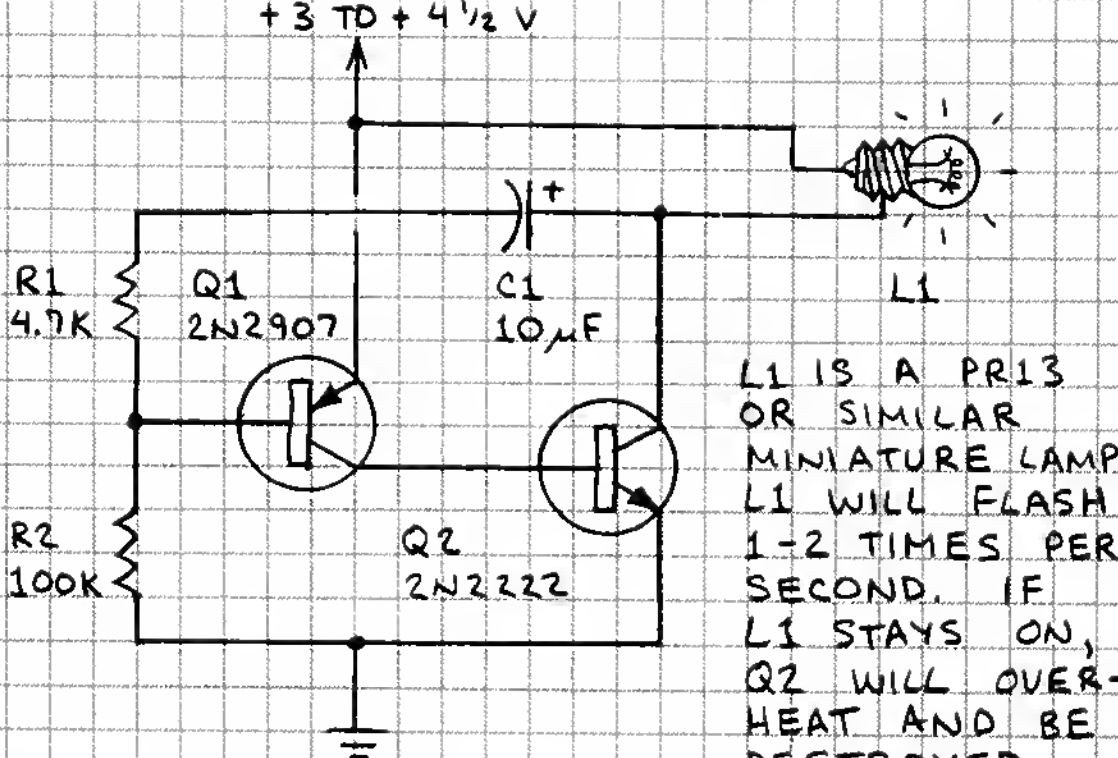
S1	FLASH RATE
OPEN	2 Hz
CLOSED	5.5 Hz

NOTE THAT THIS CIRCUIT DRIVES THE LED EVEN THOUGH THE SUPPLY VOLTAGE IS LESS THAN THE LED FORWARD VOLTAGE (~1.7 V).

DUAL LED FLASHER



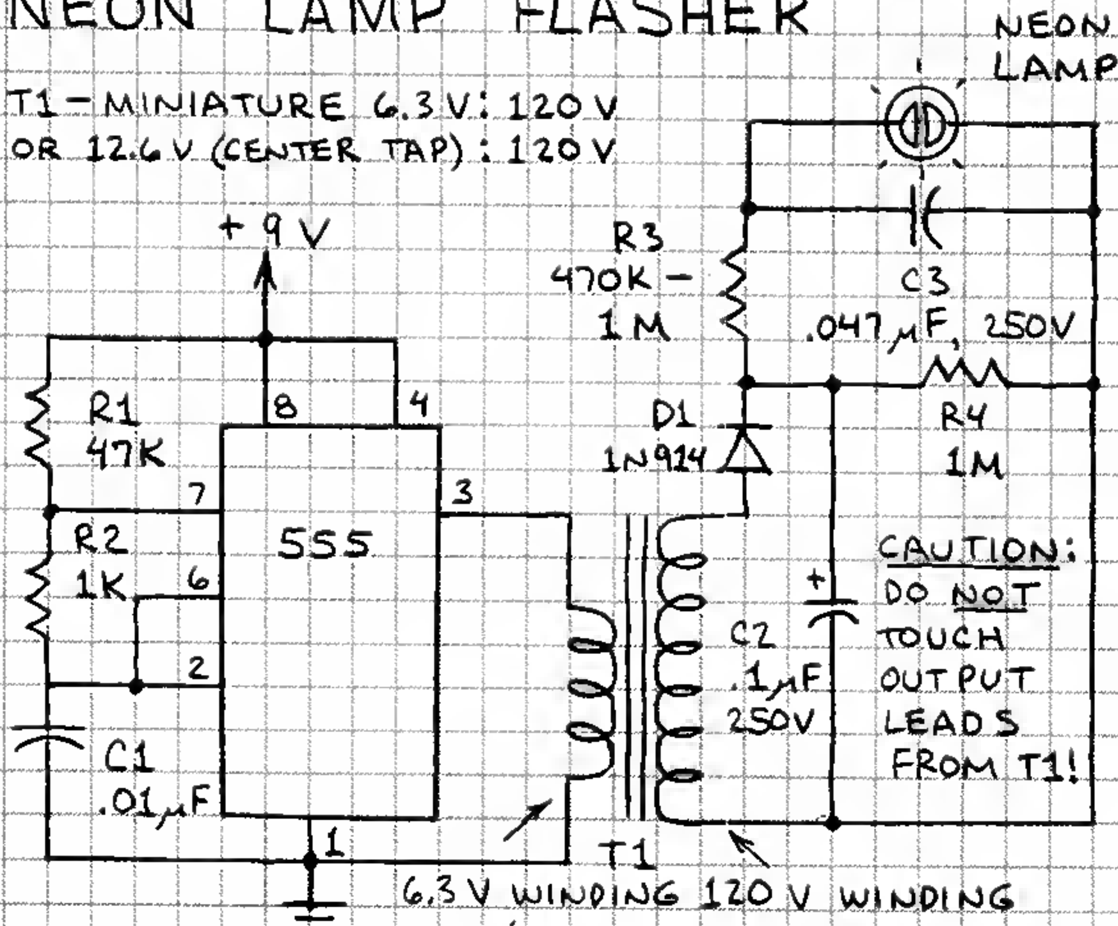
INCANDESCENT LAMP FLASHER



L1 IS A PR13 OR SIMILAR MINIATURE LAMP. L1 WILL FLASH 1-2 TIMES PER SECOND. IF L1 STAYS ON, Q2 WILL OVERHEAT AND BE DESTROYED.

NEON LAMP FLASHER

T1 - MINIATURE 6.3 V : 120 V
OR 12.6 V (CENTER TAP) : 120 V

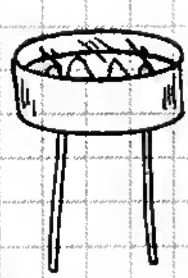


CAUTION: DO NOT TOUCH OUTPUT LEADS FROM T1!

LIGHT SENSORS

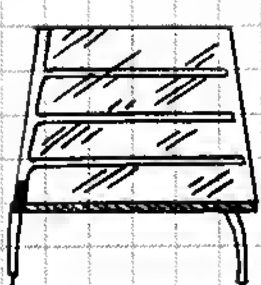
MANY LIGHT SENSORS ARE AVAILABLE FOR OPTOELECTRONIC PROJECTS. THE MOST COMMONLY USED SENSORS INCLUDE:

PHOTORESISTORS



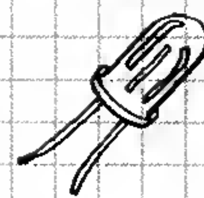
THE ELECTRICAL RESISTANCE OF A DARK PHOTORESISTOR IS ORDINARILY VERY HIGH, UP TO 1,000,000 OHMS OR MORE. THE RESISTANCE MAY FALL TO AS LITTLE AS A FEW HUNDRED OHMS WHEN THE PHOTORESISTOR IS ILLUMINATED. THE MOST COMMON SEMICONDUCTOR USED TO MAKE PHOTORESISTORS IS CADMIUM SULFIDE (CdS). IT IS PRIMARILY SENSITIVE TO GREEN LIGHT. PHOTORESISTORS EXHIBIT A "MEMORY EFFECT" IN THAT THEY MAY REQUIRE A SECOND OR MORE TO RETURN TO THEIR HIGH-RESISTANCE STATE AFTER A LIGHT SOURCE IS REMOVED. THOUGH THIS SLOWS THEIR RESPONSE TIME, THEY ARE VERY SENSITIVE AND EASY TO USE.

SOLAR CELLS



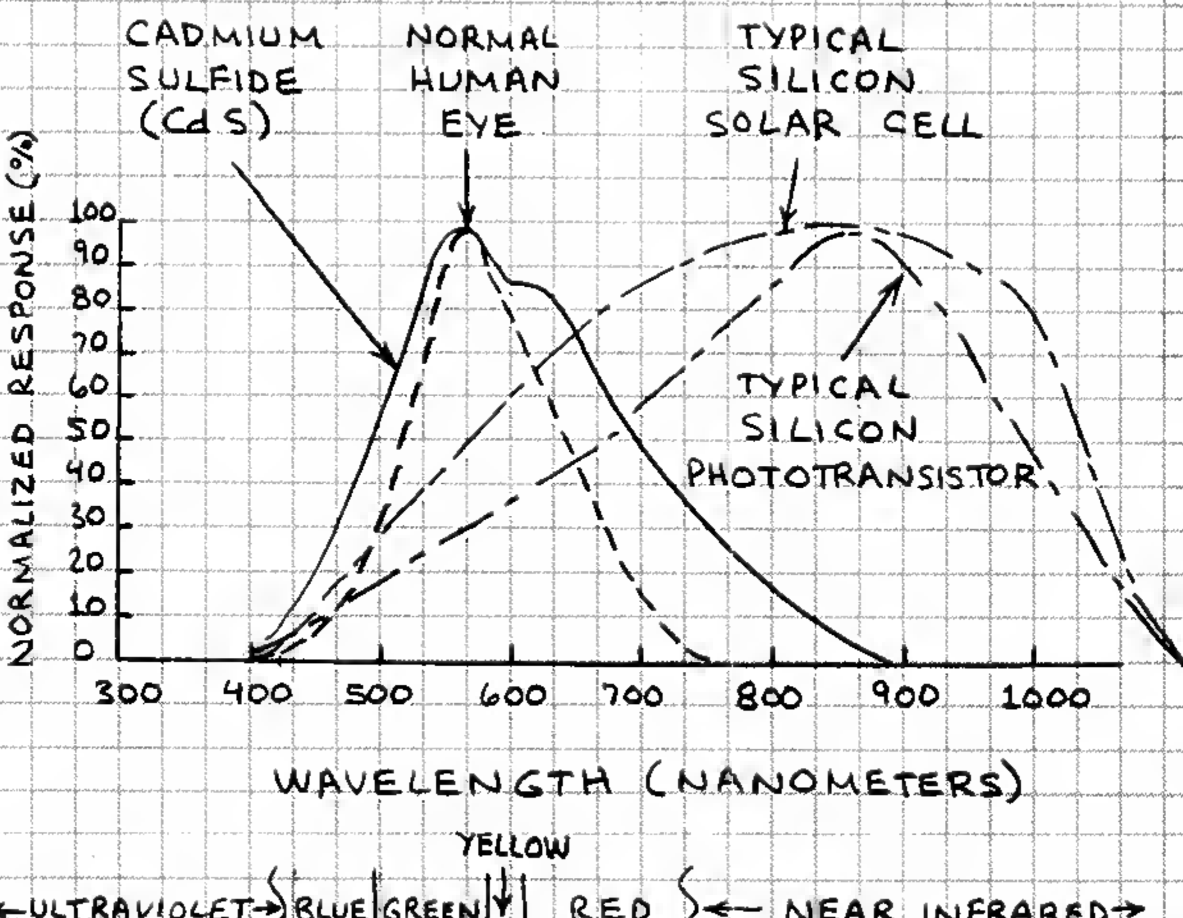
THOUGH SOLAR CELLS ARE GENERALLY USED IN SOLAR POWER SUPPLIES, THEY ARE ALSO USEFUL AS DETECTORS OF VISIBLE LIGHT AND NEAR-INFRARED RADIATION. THEY ARE AVAILABLE IN MANY DIFFERENT SIZES AND SHAPES. SINCE A TYPICAL SOLAR CELL RESPONDS TO CHANGES IN LIGHT INTENSITY WITHIN 20 MICROSECONDS, SOLAR CELLS CAN DETECT VOICE MODULATED LIGHTWAVE SIGNALS.

PHOTOTRANSISTORS



ALL TRANSISTORS ARE LIGHT SENSITIVE. PHOTOTRANSISTORS ARE DESIGNED TO EXPLOIT THIS PHENOMENON. THOUGH A BIPOLAR TRANSISTOR HAS THREE LEADS, A PHOTOTRANSISTOR MAY NOT HAVE A BASE LEAD. MOST PHOTOTRANSISTORS ARE NPN DEVICES WITH A BASE REGION MUCH LARGER THAN THAT OF A STANDARD NPN TRANSISTOR. THEY HAVE A RESPONSE TIME OF 1 MICROSECOND IN SOME CIRCUITS. THE DARLINGTON PHOTOTRANSISTOR INCLUDES A SECOND ON-CHIP TRANSISTOR TO AMPLIFY THE SIGNAL GENERATED BY THE PHOTOTRANSISTOR. IT GIVES MORE SENSITIVITY BUT IS SLOWER.

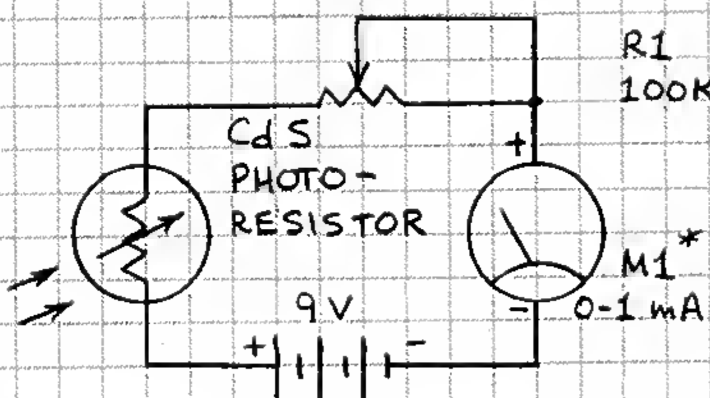
SENSOR SPECTRAL RESPONSE



SIMPLE LIGHT METERS

THOUGH VERY SIMPLE, THESE LIGHT METER CIRCUITS ARE VERY SENSITIVE.

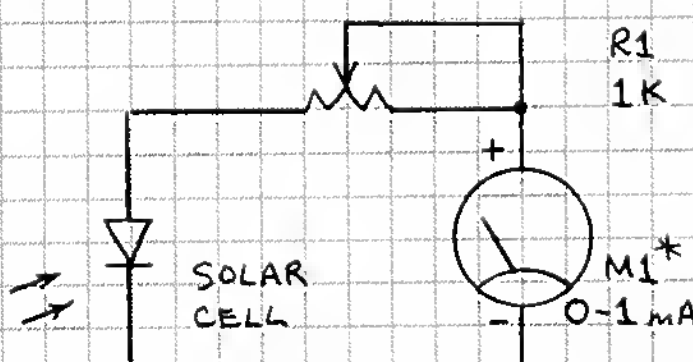
PHOTORESISTOR



OK TO TRY OTHER BATTERY VOLTAGES. AVOID RAPID INCREASE IN LIGHT THAT MIGHT HARM THE METER!

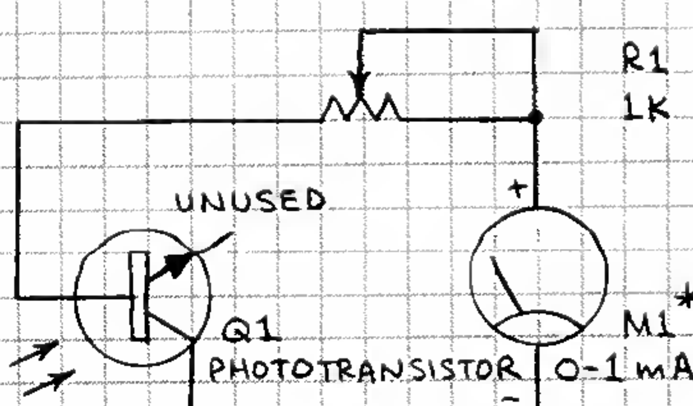
* ANALOG MULTITESTER

SOLAR CELL



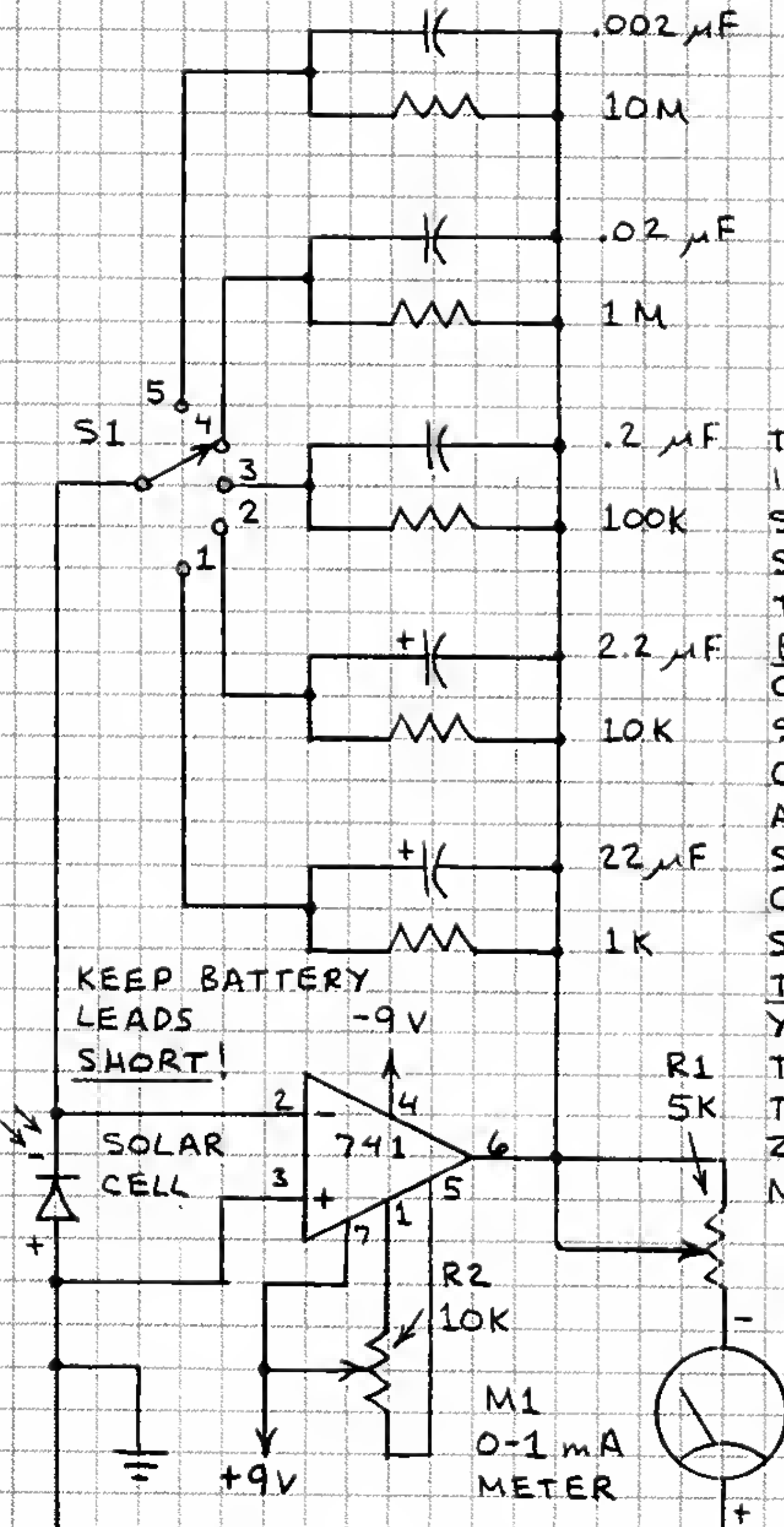
TWO OR MORE SOLAR CELLS IN PARALLEL WILL GIVE HIGHER SENSITIVITY.

PHOTOTRANSISTOR



THE BASE-COLLECTOR JUNCTION OF Q1 FORMS A PHOTODIODE OR MINIATURE SOLAR CELL.

ULTRA-SENSITIVE LIGHT METER



FULL SCALE READINGS (SWITCH S1)

1 - 100 µA
2 - 10 µA
3 - 1 µA
4 - .1 µA
5 - .01 µA

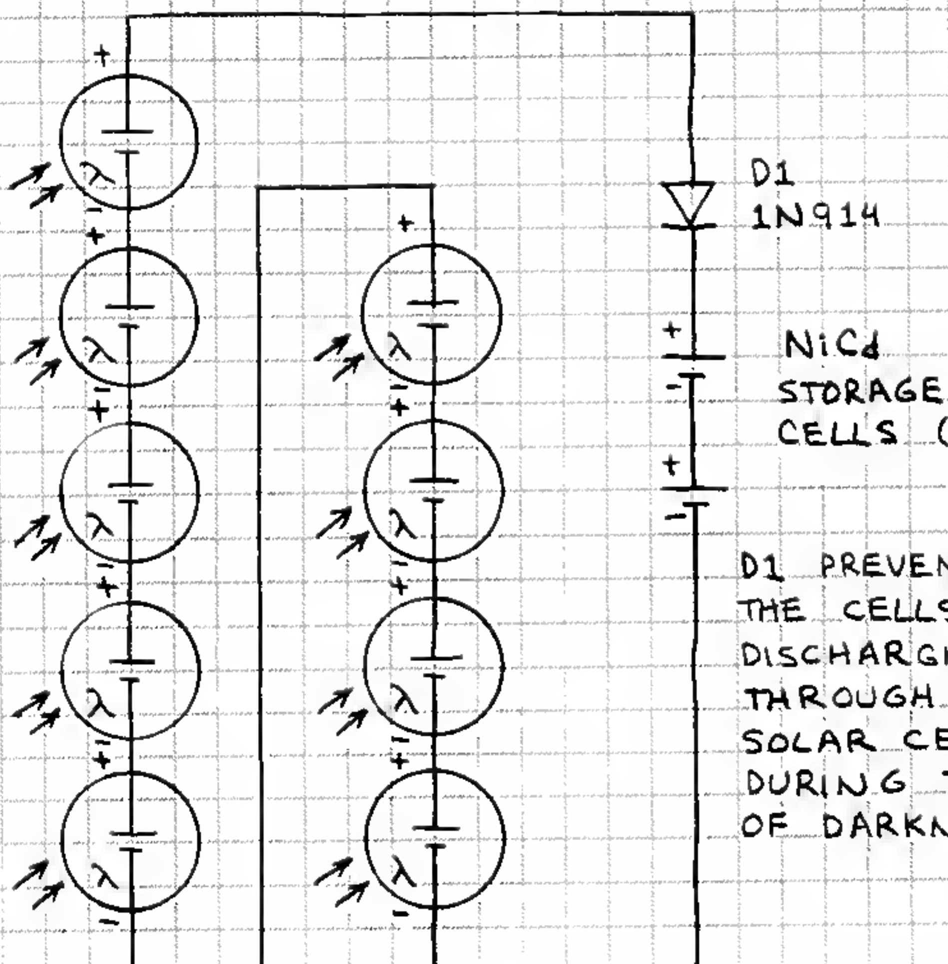
THIS CIRCUIT IS VERY SENSITIVE. ALWAYS SET SWITCH S1 TO POSITION 1 BEFORE THE CIRCUIT IS SWITCHED ON. CAREFULLY ADJUST R1 TO SET METER TO 0 WHEN THE SOLAR CELL IS TOTALLY DARK. YOU MAY HAVE TO ADJUST R2 TO PROPERLY ZERO THE METER.

CAUTION: EXCESSIVE LIGHT WILL "SLAM" THE METER'S NEEDLE.

IF ULTRA-HIGH SENSITIVITY IS NOT REQUIRED, OMIT THE UPPER RESISTORS AND USE THE LOWER TWO OR THREE.

SOLAR BATTERY CHARGER

AN ARRAY OF SOLAR CELLS WILL RECHARGE ONE OR MORE NICKEL-CADMIUM (NiCd) STORAGE CELLS. FOR EXAMPLE, NINE SOLAR CELLS CONNECTED IN SERIES WILL CHARGE TWO NiCd CELLS CONNECTED IN SERIES:



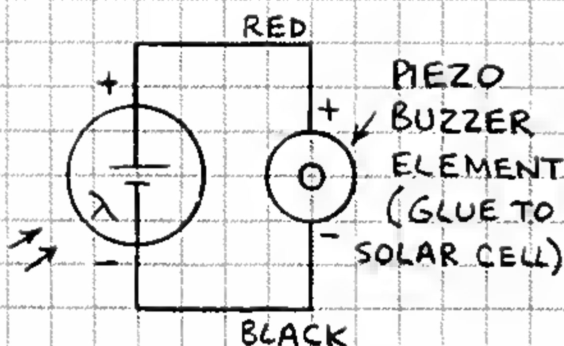
D1 PREVENTS THE CELLS FROM DISCHARGING THROUGH THE SOLAR CELLS DURING TIMES OF DARKNESS.

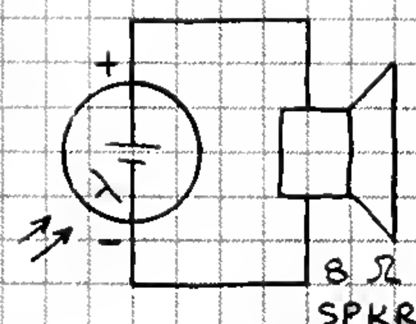
A SINGLE SILICON SOLAR CELL PRODUCES AN OPEN-CIRCUIT POTENTIAL OF FROM 0.45 TO 0.5 VOLT. A SINGLE CELL CAN PRODUCE A CURRENT OF AN AMPERE OR MORE DEPENDING ON THE AREA OF THE CELL AND THE SUNLIGHT INTENSITY. <u>IMPORTANT</u>: THE SOLAR CELL CURRENT MUST <u>NOT</u> EXCEED THE SAFE CHARGING RATE OF THE NiCd CELLS. THE OUTPUT VOLTAGE OF CELLS IN SERIES IS THE SUM OF THE CELL VOLTAGES. SOLAR CELLS ARE <u>FRAGILE</u>. CONNECT THEM WITH WRAPPING WIRE. MOUNT WITH SILICONE SEALANT.

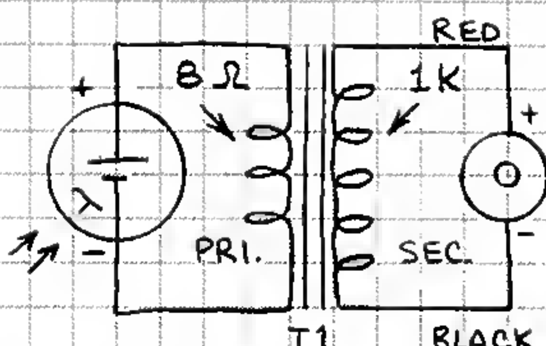
SOLAR-POWERED CIRCUITS

ULTRA-SIMPLE LIGHT RECEIVERS

THESE THREE RECEIVER CIRCUITS REQUIRE NO SOURCE OF POWER BEYOND THE LIGHTWAVE SIGNAL THEY RECEIVE. THEY WILL TRANSFORM AN AUDIO-FREQUENCY MODULATED LIGHT BEAM DIRECTLY INTO SOUND. THEY CAN BE USED TO CHECK INFRARED REMOTE CONTROL TRANSMITTERS AND TO RECEIVE VOICE OR TONE LIGHTWAVE SIGNALS.

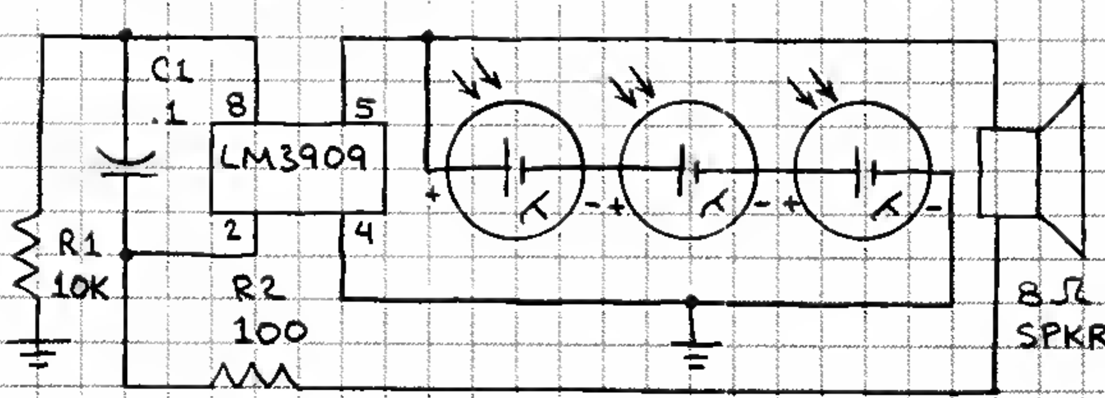






T1 IS A MINIATURE AUDIO-OUTPUT TRANSFORMER.
PRI - PRIMARY
SEC - SECONDARY
THIS CIRCUIT HAS THE LOUDEST OUTPUT.

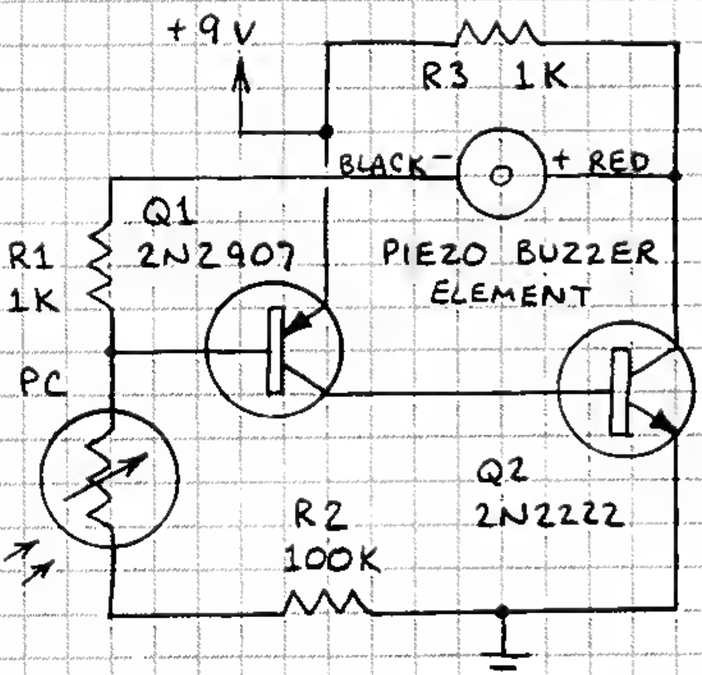
SUN-POWERED OSCILLATOR



LIGHT-SENSITIVE OSCILLATORS

THESE SIMPLE CIRCUITS ARE SOMETIMES CALLED AUDIBLE LIGHT PROBES. IF THE CIRCUIT IS ADJUSTED SO THE OSCILLATION JUST CEASES WHEN THE SENSOR IS DARK, THE CIRCUIT WILL EMIT CLICKS IN RESPONSE TO A CANDLE FLAME UP TO 100 FEET AWAY.

TRANSISTOR

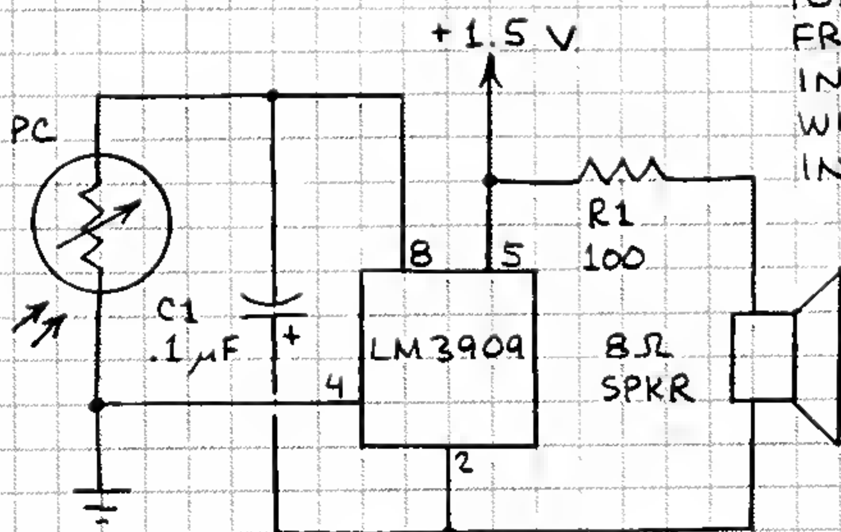


TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.

THIS CIRCUIT CAN EASILY BE INSTALLED IN A VERY SMALL PLASTIC ENCLOSURE.

PC – CdS PHOTOCELL (PHOTORESISTOR)

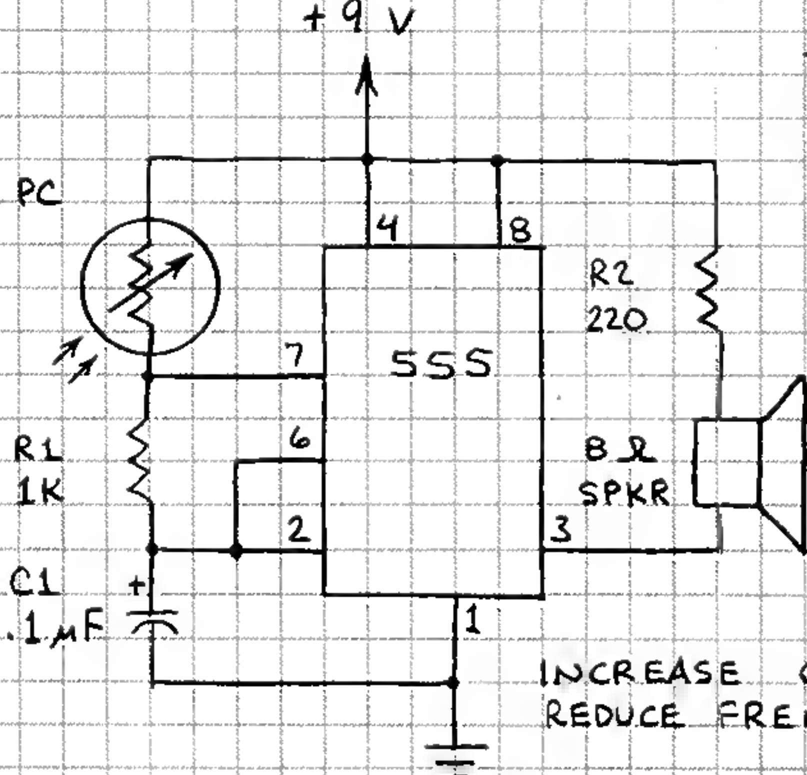
LM3909



TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.

PC – CdS PHOTOCELL (PHOTORESISTOR)

555 (BASIC OSCILLATOR)



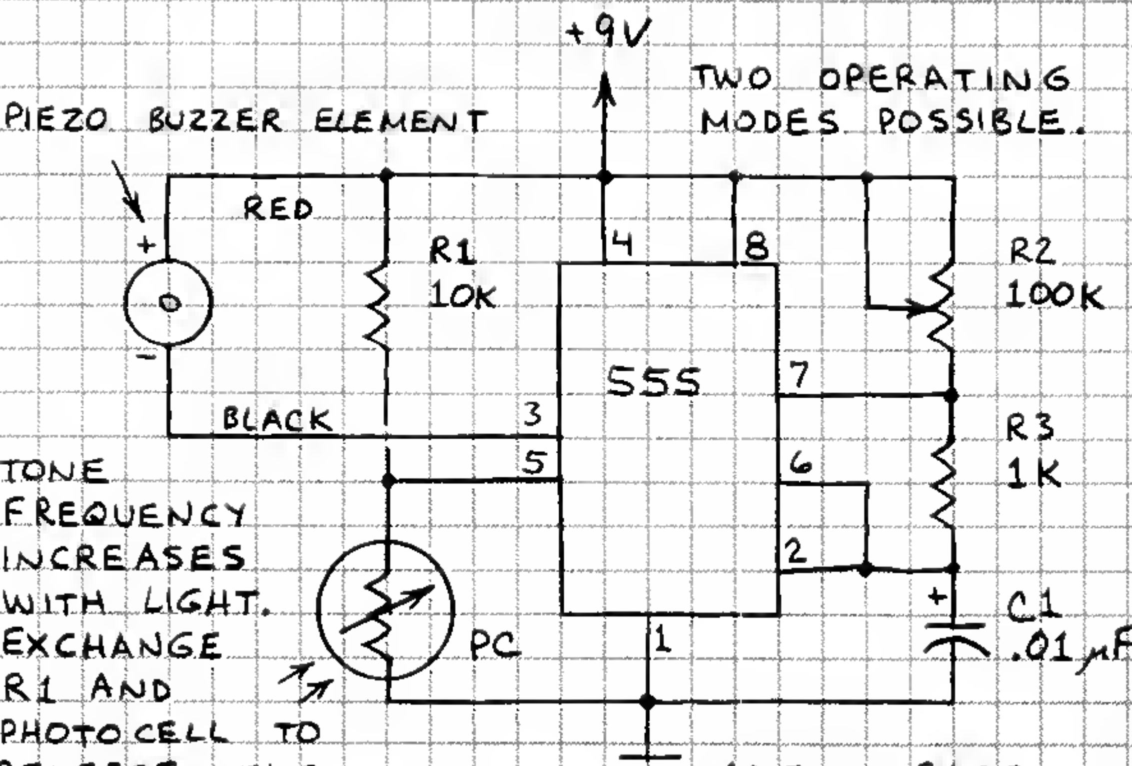
TONE FREQUENCY INCREASES WITH LIGHT INTENSITY.

CIRCUIT BELOW SHOWS HOW TO USE PIEZO-BUZZER OUTPUT.

INCREASE C1 TO REDUCE FREQUENCY.

555 (VOLTAGE-CONTROLLED OSCILLATOR)

TWO OPERATING MODES POSSIBLE.

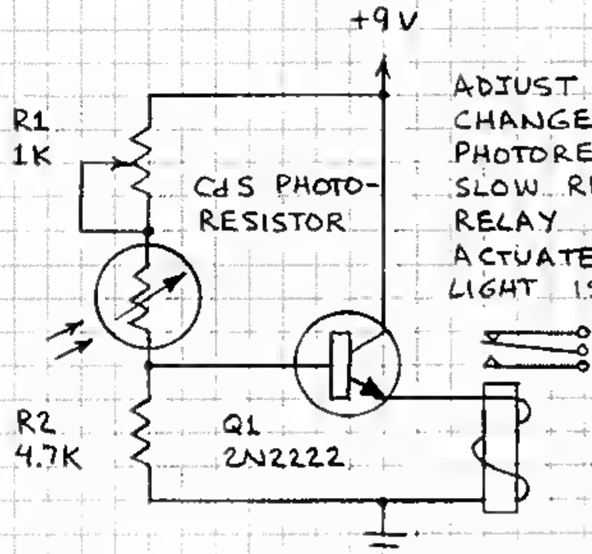


TONE FREQUENCY INCREASES WITH LIGHT. EXCHANGE R1 AND PHOTOCELL TO REVERSE THIS OPERATING MODE.

ADJUST BASE FREQUENCY VIA R2.

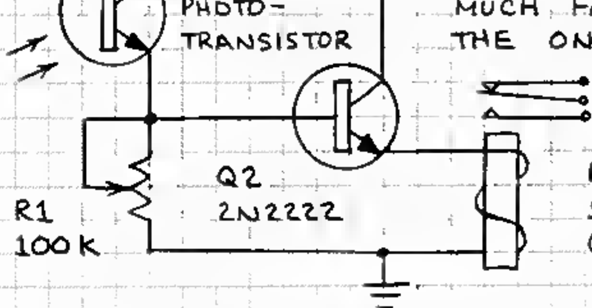
LIGHT-ACTIVATED RELAYS

PHOTORESISTOR



ADJUST R1 TO CHANGE SENSITIVITY. PHOTORESISTORS HAVE SLOW RESPONSE, SO RELAY WILL REMAIN ACTUATED BRIEFLY AFTER LIGHT IS REMOVED.

PHOTOTRANSISTOR

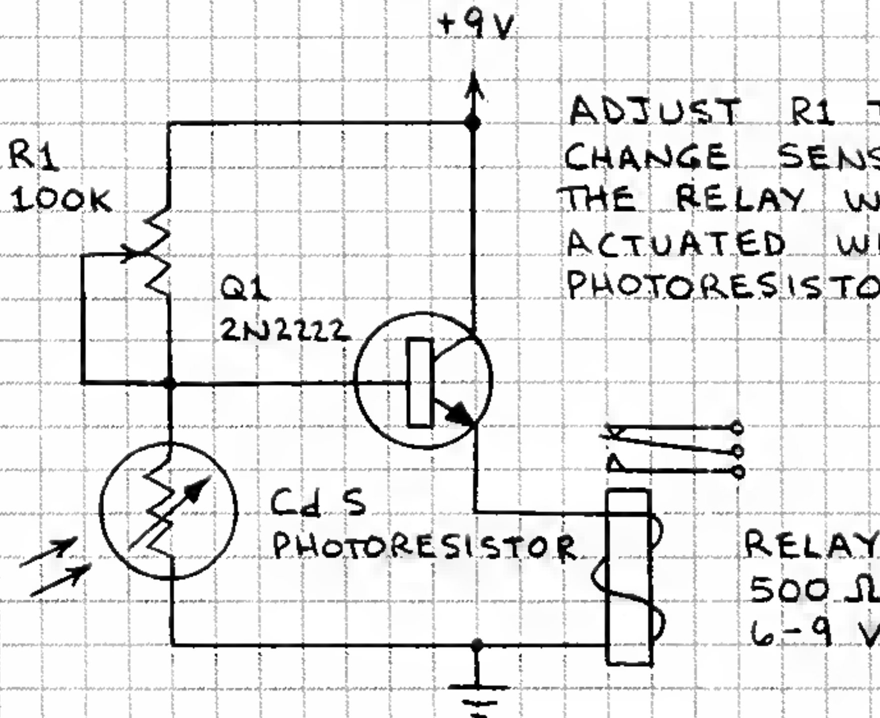


ADJUST R1 TO CHANGE SENSITIVITY. THIS CIRCUIT RESPONDS MUCH FASTER THAN THE ONE ABOVE.

NOTE: USE LIGHT SHIELD AT DETECTOR OF BOTH CIRCUITS TO PREVENT FALSE TRIGGERING.

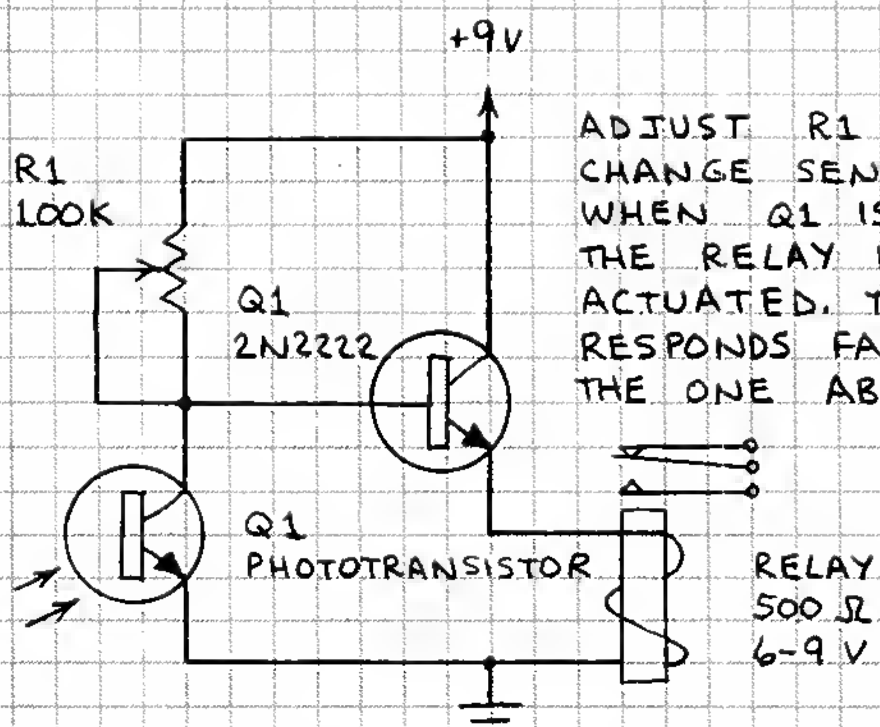
DARK-ACTIVATED RELAYS

PHOTORESISTOR



ADJUST R1 TO CHANGE SENSITIVITY. THE RELAY WILL BE ACTUATED WHEN THE PHOTORESISTOR IS DARK.

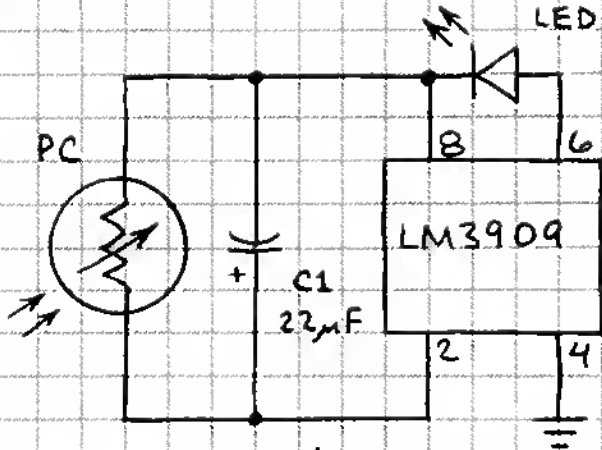
PHOTOTRANSISTOR



ADJUST R1 TO CHANGE SENSITIVITY. WHEN Q1 IS DARK THE RELAY IS ACTUATED. THIS CIRCUIT RESPONDS FASTER THAN THE ONE ABOVE.

DARK-ACTIVATED LED FLASHERS

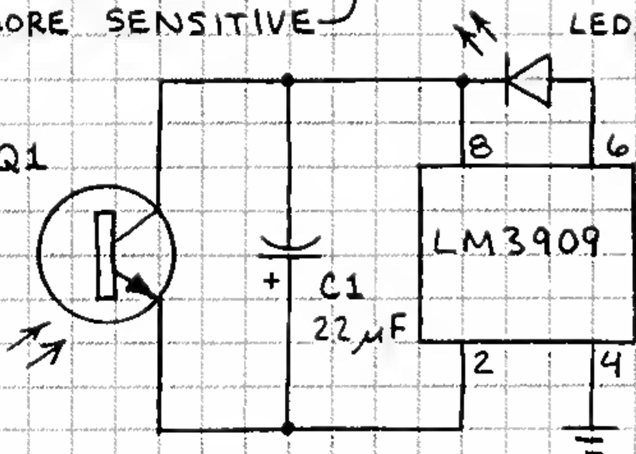
LM3909



LED FLASHES WHEN PC IS DARK.

PC–CdS PHOTOCELL (PHOTORESISTOR)

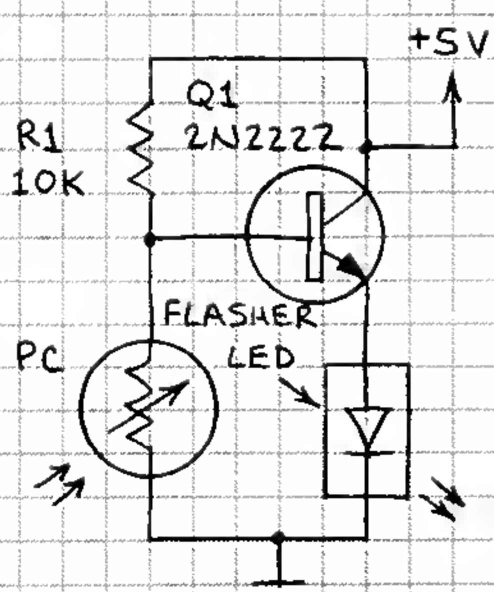
THIS CIRCUIT IS MORE SENSITIVE

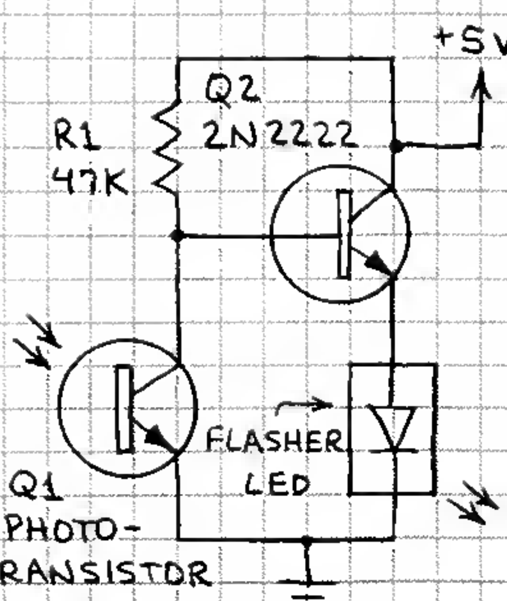


LED FLASHES WHEN Q1 IS DARK.

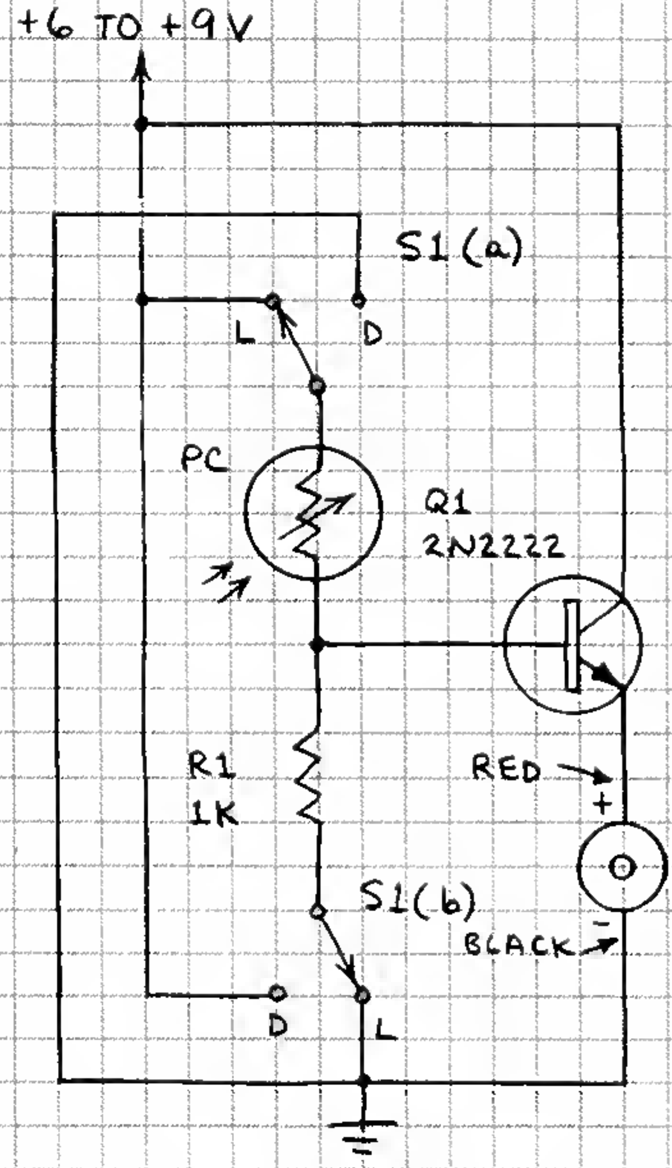
Q1 – PHOTO-TRANSISTOR

FLASHER LED





LIGHT/DARK ACTIVATED ALERTER



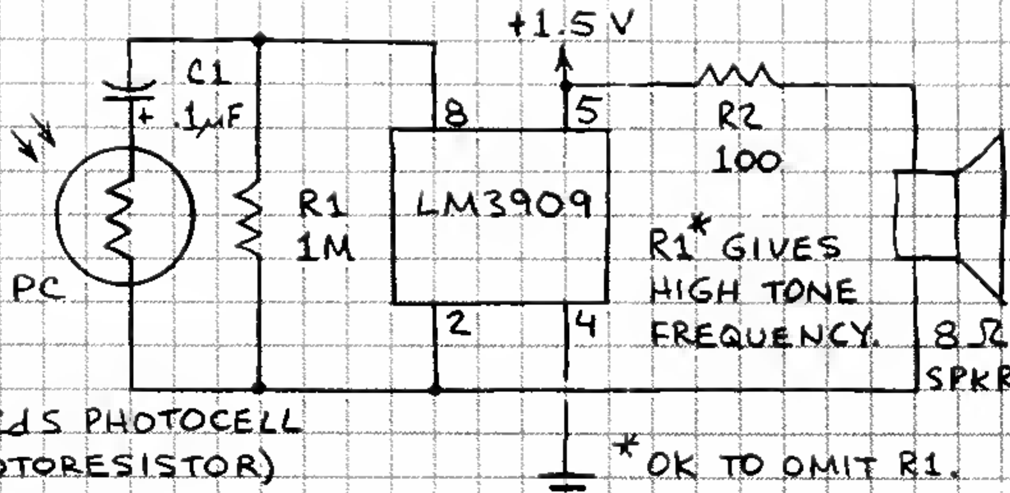
WHEN S1 IS AT POSITION L, THE PIEZO BUZZER IS ACTIVATED WHEN LIGHT STRIKES THE PC. WHEN S1 IS AT POSITION D, THE BUZZER IS ACTIVATED WHEN THE PC IS DARK.

THIS CIRCUIT AND THE ONE BELOW CAN BE USED TO DETECT OPEN CASH DRAWERS AND REFRIGERATOR DOORS.

PIEZO BUZZER

PC - CdS PHOTOCELL (PHOTORESISTOR)

LIGHT-ACTIVATED TONE



R1* GIVES HIGH TONE FREQUENCY.

PC-CdS PHOTOCELL (PHOTORESISTOR)

*OK TO OMIT R1.

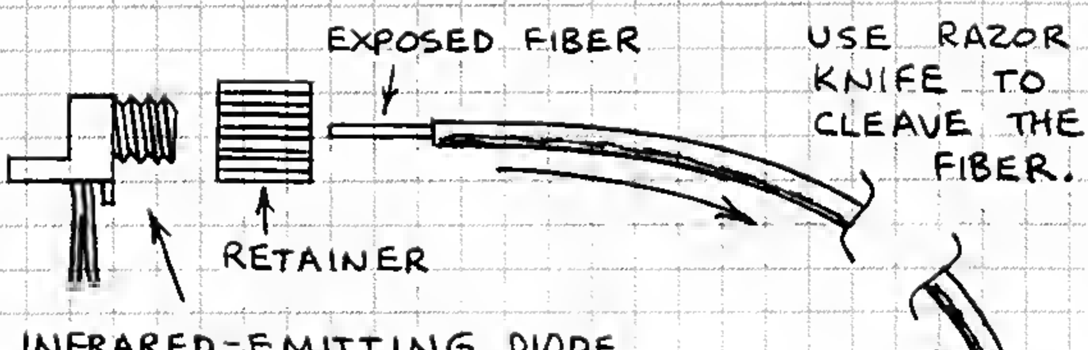
LIGHTWAVE COMMUNICATIONS

IT IS RELATIVELY EASY TO TRANSMIT VOICE OR SIGNALS BY MEANS OF VISIBLE LIGHT OR INFRARED RADIATION. THE RADIATION CAN BE SENT DIRECTLY THROUGH THE AIR OR CHANNELED THROUGH AN OPTICAL FIBER. THE INFORMATION ON THESE TWO PAGES WILL ASSIST YOU IN USING THE LIGHTWAVE COMMUNICATION CIRCUITS THAT FOLLOW.

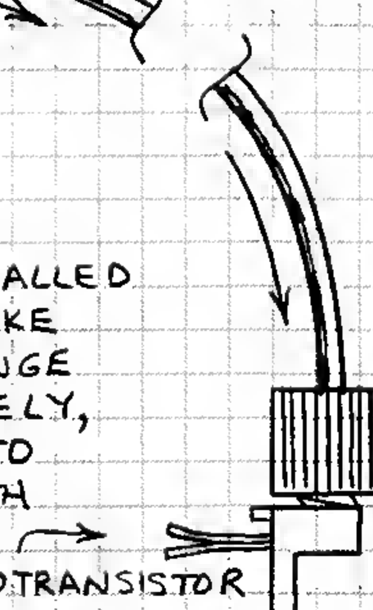
SUITABLE COMPONENTS

SMALL INCANDESCENT LAMPS CAN BE USED TO SEND VOICE AND AUDIO-FREQUENCY SIGNALS. FOR BEST RESULTS, USE HIGH-POWER, NEAR-INFRARED-EMITTING DIODES. SUITABLE DETECTORS INCLUDE PHOTODIODES, PHOTOTRANSISTORS, AND SOLAR CELLS.

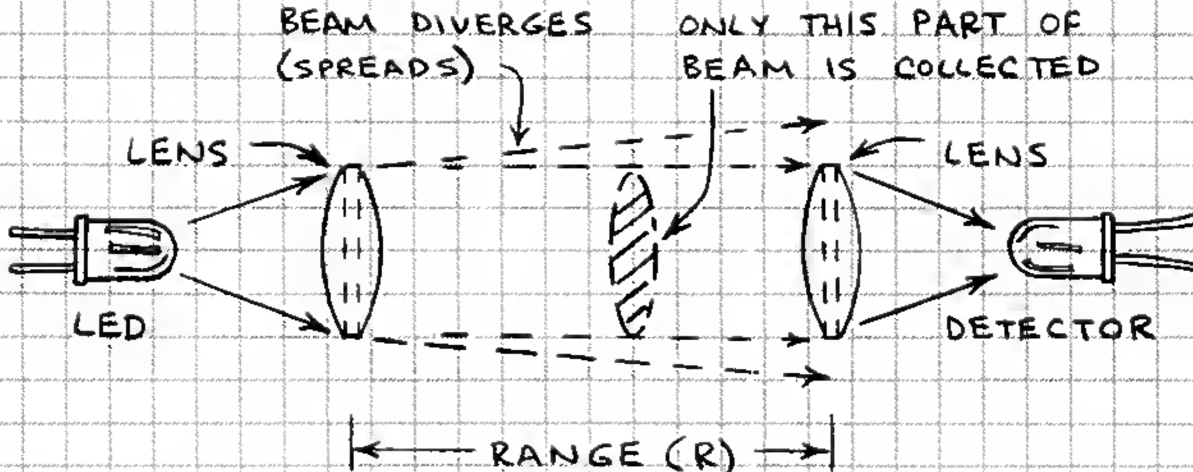
OPTICAL FIBER LINKS



LEDs AND DETECTORS INSTALLED IN PLASTIC RECEPTACLES LIKE THESE SIMPLIFY SHORT-RANGE FIBER LINKS. ALTERNATIVELY, CONNECT FIBER DIRECTLY TO LEDs AND DETECTORS WITH EPOXY AND HEAT-SHRINKABLE TUBING.



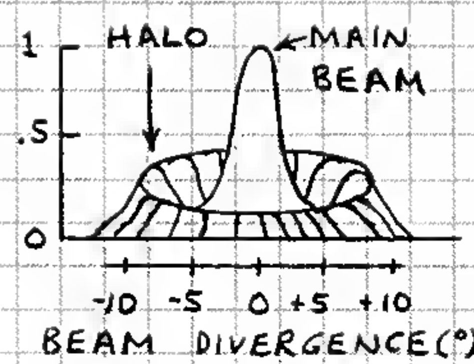
FREE-SPACE LINKS



A PAIR OF LENSES WILL GREATLY INCREASE THE RANGE. USE LENSES FROM MAGNIFYING GLASS OR ORDER FROM SCIENCE SUPPLY FIRM.

FOR BEST RESULTS SHIELD DETECTOR FROM EXTERNAL LIGHT WITH HOLLOW TUBE LINED WITH BLACK PAPER OR COATED WITH FLAT BLACK PAINT. A PIECE OF DEVELOPED COLOR FILM MAKES A GOOD NEAR-INFRARED FILTER.

PRACTICE FOCUSING AN INFRARED LED BY FIRST USING A RED LED. NOTE THAT RAW BEAM FROM CLEAR ENCAPSULATED LED SHOWS BRIGHT SQUARE (THE CHIP) INSIDE DIFFUSE RED HALO. THE HALO IS NOT ELIMINATED BY AN EXTERNAL LENS.



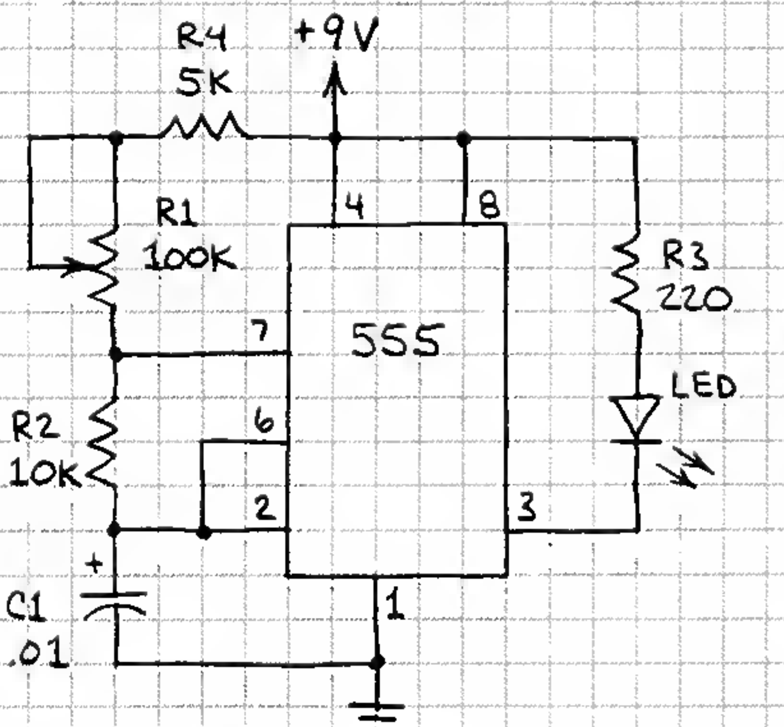
TYPICAL BEAM

FOCUSING AND ALIGNING AN INFRARED FREE-SPACE LINK IS TRICKY. MOUNT THE TRANSMITTER ON A TRIPOD FOR BEST RESULTS. DOUBLING THE DIAMETER OF THE RECEIVER LENS WILL APPROXIMATELY DOUBLE THE MAXIMUM RANGE. FOR MORE DETAILS, SEE "A PRACTICAL INTRODUCTION TO LIGHTWAVE COMMUNICATIONS" (FORREST MIMS, SAMS, 1982).

LIGHTWAVE TONE TRANSMITTERS

SIMPLE LIGHTWAVE TONE TRANSMITTERS ARE VERY USEFUL WHEN TESTING LIGHTWAVE RECEIVERS AND AS CODE AND REMOTE CONTROL TRANSMITTERS. THESE CIRCUITS AND THE ONE ON PAGE 40 CAN BE BUILT IN SMALL PLASTIC BOXES.

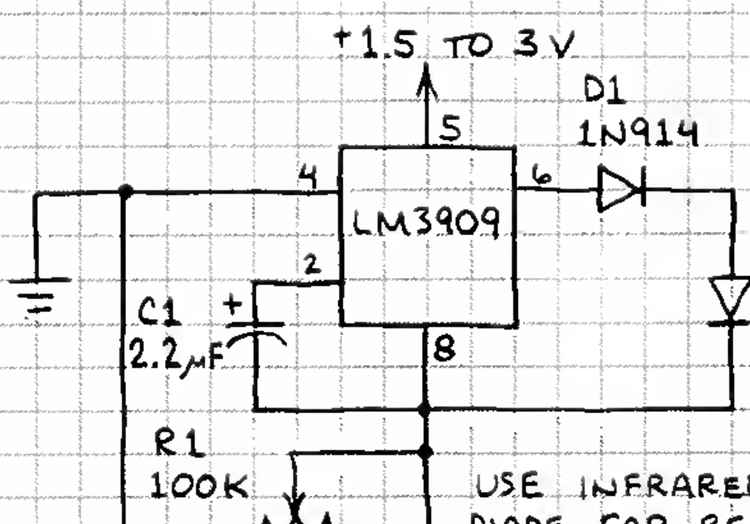
555 TRANSMITTER



R1 CONTROLS PULSE RATE. USE INFRARED-EMITTING DIODE FOR BEST RESULTS.

DUTY CYCLE IS ABOUT 50%.

LM3909 TRANSMITTER



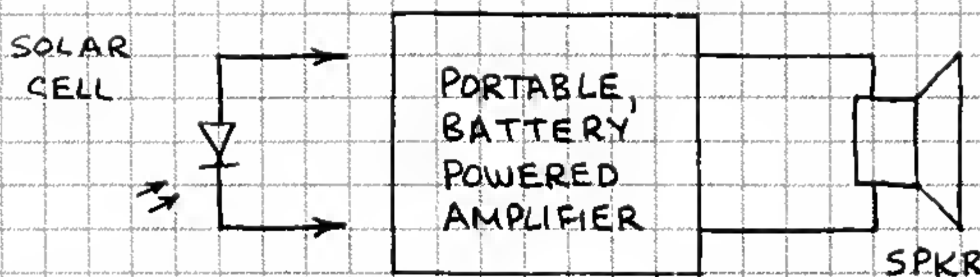
OMIT D1 IF RED LED USED.

USE INFRARED-EMITTING DIODE FOR BEST RESULTS.

SIMPLE LIGHTWAVE RECEIVERS

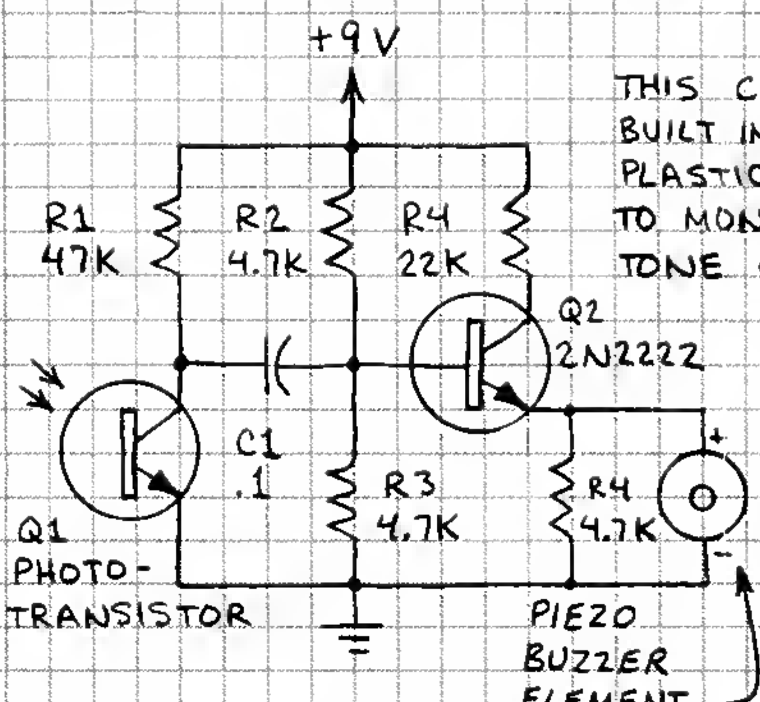
CIRCUITS CAPABLE OF RECEIVING MODULATED LIGHTWAVE SIGNALS ARE EASY TO BUILD. THREE ADVANCED RECEIVERS ARE SHOWN ON THE FOLLOWING PAGES. HERE ARE TWO VERY SIMPLE RECEIVERS (ALSO SEE PAGE 25):

"INSTANT" LIGHTWAVE RECEIVER



CONNECT THE SOLAR CELL DIRECTLY TO THE INPUT JACK OF THE AMPLIFIER. THE SPEAKER MAY BE BUILT-IN OR EXTERNAL. THIS RECEIVER WILL DETECT TONE AND VOICE MODULATED SIGNALS.

TWO-TRANSISTOR RECEIVER

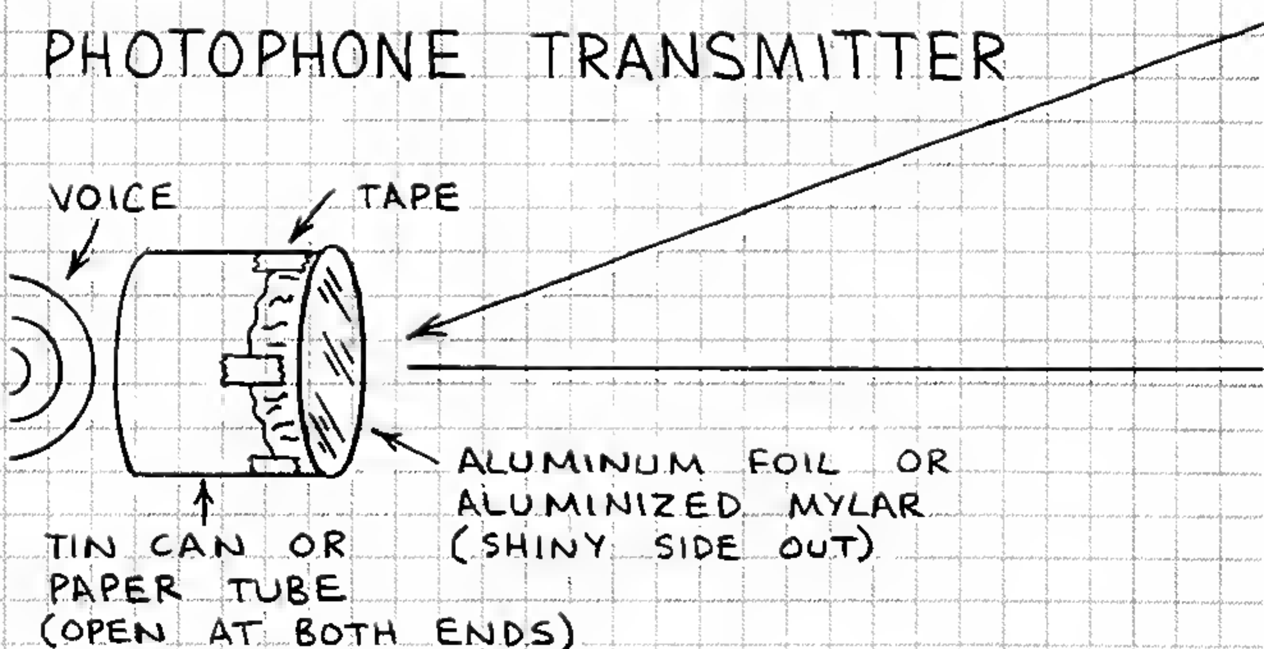


THIS CIRCUIT CAN BE BUILT INTO A SMALL PLASTIC BOX AND USED TO MONITOR LIGHTWAVE TONE OR VOICE TRANSMITTERS. TO USE AN 8 Ω SPEAKER, REPLACE BUZZER ELEMENT WITH PRIMARY OF 1K:8 Ω AUDIO TRANSFORMER. CONNECT SPKR TO 8 Ω SIDE.

THE PHOTOPHONE

ON FEBRUARY 19, 1880, ALEXANDER GRAHAM BELL AND SUMNER TAINTER, PROF. BELL'S LABORATORY ASSISTANT, BECAME THE FIRST PEOPLE TO TRANSMIT THEIR VOICES OVER A BEAM OF ELECTROMAGNETIC RADIATION. BELL CALLED HIS INVENTION THE PHOTOPHONE AND SAID IT WAS FUNDAMENTALLY A GREATER INVENTION THAN THE TELEPHONE. THE PHOTOPHONE IS EASILY DUPLICATED.

PHOTOPHONE TRANSMITTER



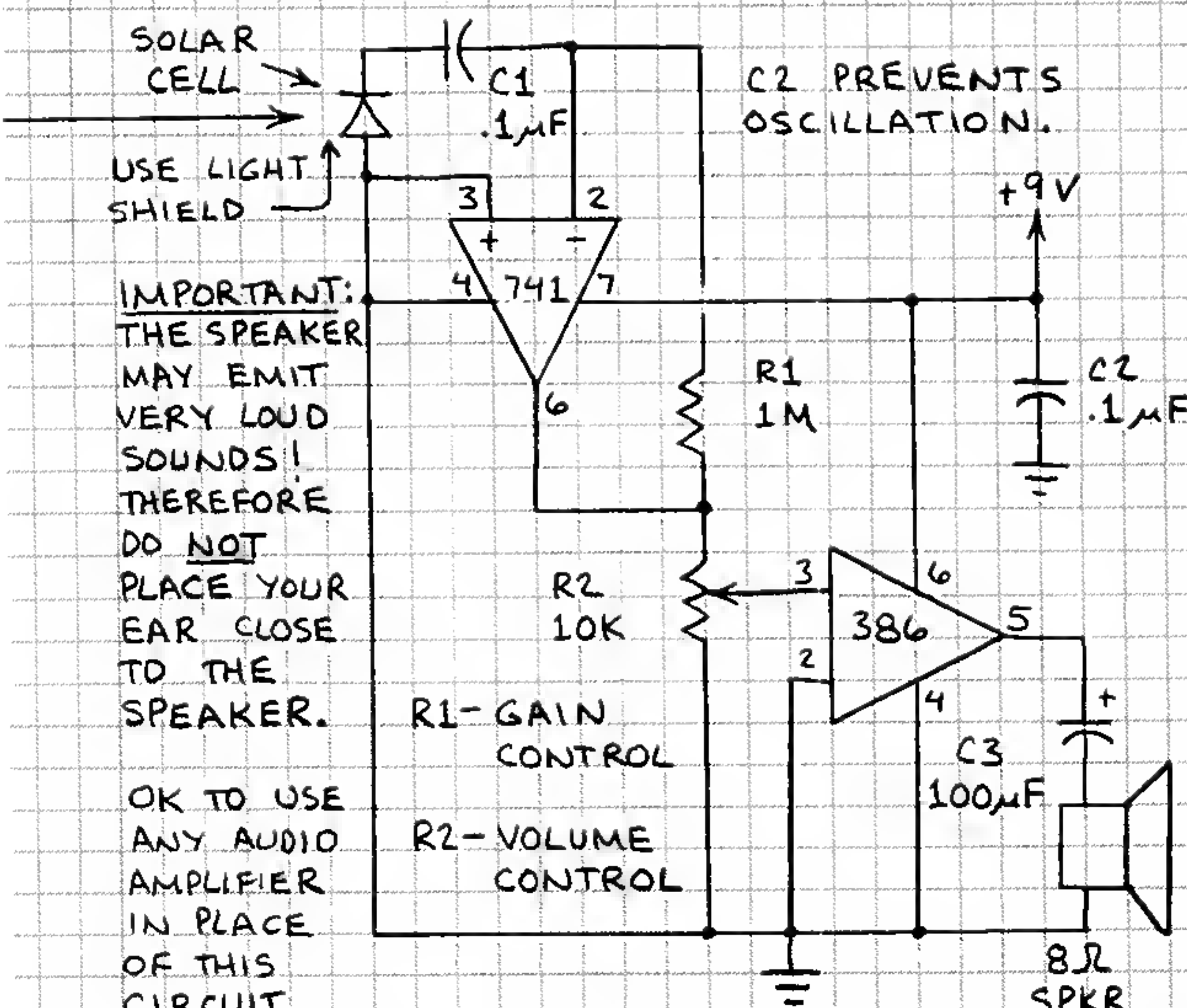
THE ALUMINUM FOIL OR ALUMINIZED FILM SHOULD BE STRETCHED <u>TIGHT</u> OVER THE CAN OR TUBE AND HELD IN PLACE WITH TAPE OR A RUBBER BAND. BE SURE THE SHINY SIDE OF THE FOIL OR FILM FACES OUTWARD. TEST THE TRANSMITTER BY REFLECTING SUNLIGHT FROM IT TO A WALL SOME DISTANCE AWAY. THE REFLECTED SUNLIGHT SHOULD FORM A DISTINCT SPOT. IF NOT, THE FOIL OR FILM IS NOT TIGHT ENOUGH. FOR BEST RESULTS, MOUNT THE TRANSMITTER ON A PHOTOGRAPHER'S TRIPOD TO SIMPLIFY AIMING THE BEAM.

PHOTOPHONE RECEIVER

BELL'S PHOTOPHONES USED A SELENIUM DETECTOR IN SERIES WITH A BATTERY AND TELEPHONE RECEIVER.

THIS PHOTOPHONE RECEIVER USES A SILICON SOLAR CELL SO NO LENS IS NECESSARY. TO USE A PHOTOTRANSISTOR, SEE PAGE 39.

CAUTION: BOTH TRANSMITTER AND RECEIVER OPERATORS MUST WEAR DARK SUNGLASSES AND AVOID STARING AT REFLECTED SUNLIGHT!

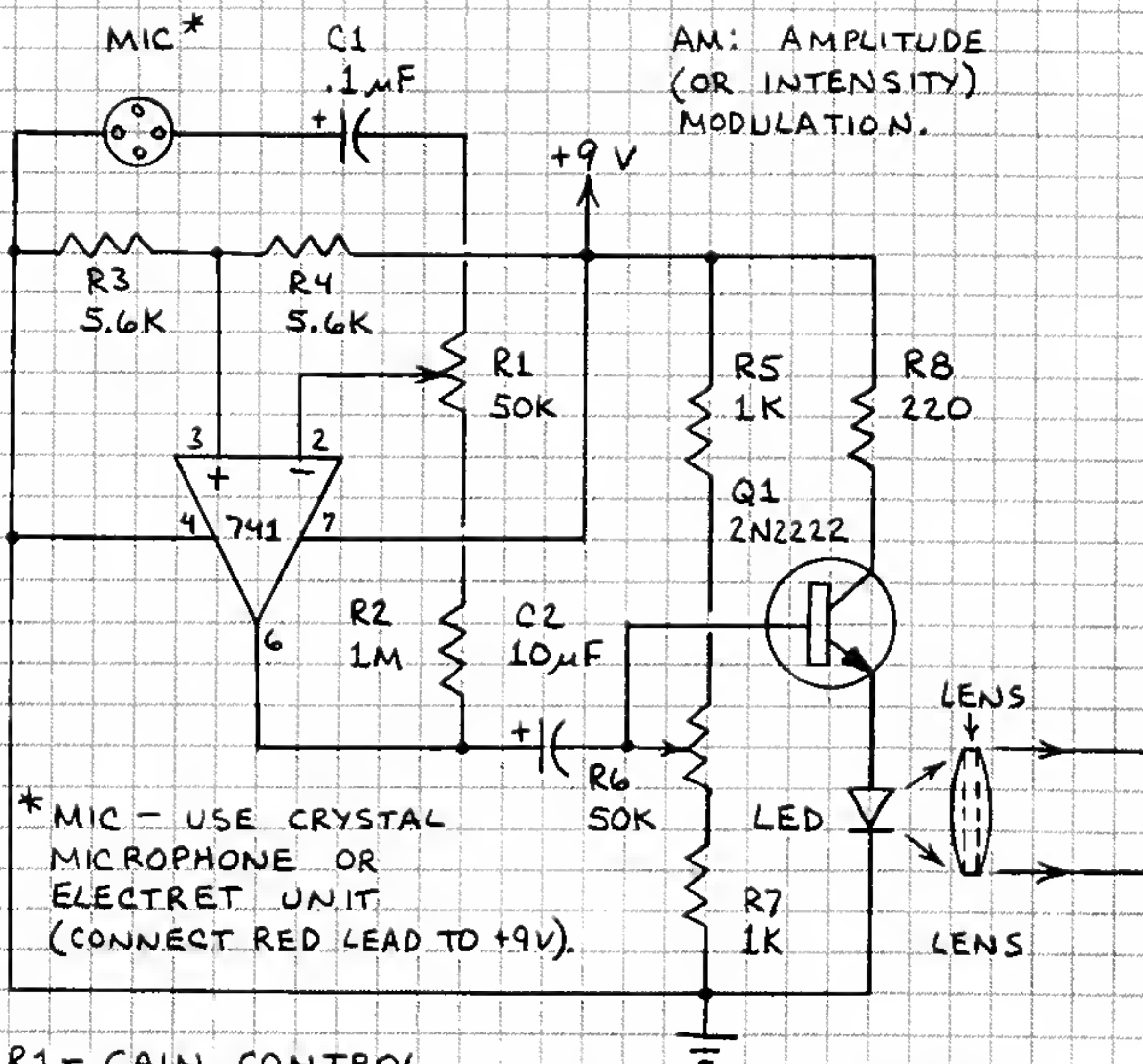


IMPORTANT: THE SPEAKER MAY EMIT VERY LOUD SOUNDS! THEREFORE DO NOT PLACE YOUR EAR CLOSE TO THE SPEAKER.

OK TO USE ANY AUDIO AMPLIFIER IN PLACE OF THIS CIRCUIT.

AM LIGHTWAVE TRANSMITTER

AM: AMPLITUDE (OR INTENSITY) MODULATION.



*MIC — USE CRYSTAL MICROPHONE OR ELECTRET UNIT (CONNECT RED LEAD TO +9V).

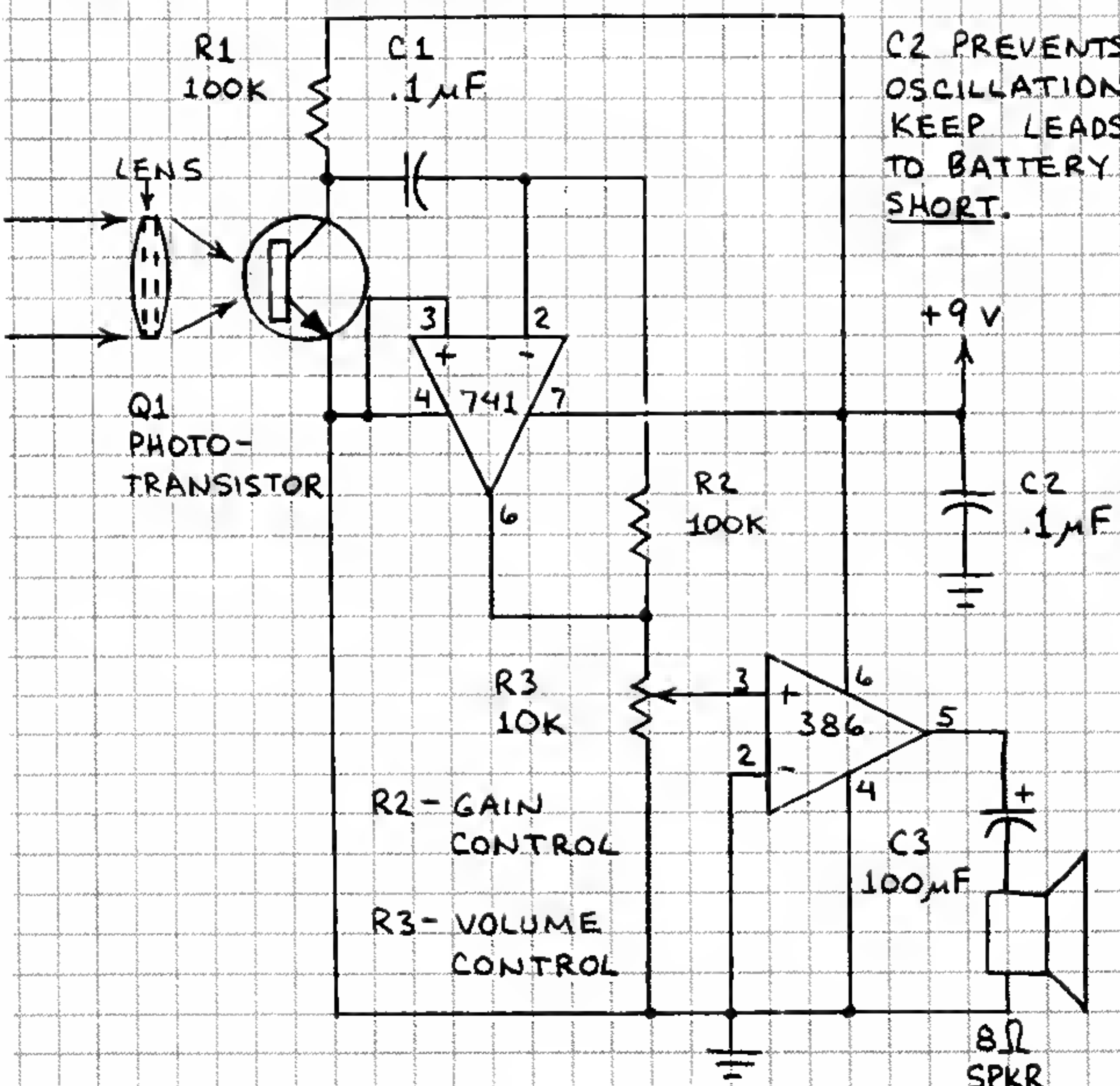
R1 — GAIN CONTROL
R6 — LED BIAS CONTROL. ADJUST R6 FOR BEST SOUND QUALITY.
R8 — LIMITS CURRENT APPLIED TO LED.

THE 741 AMPLIFIES VOICE SIGNALS FROM THE MICROPHONE AND COUPLES THEM THROUGH C2 TO MODULATOR TRANSISTOR Q1. USE A HIGH-BRIGHTNESS RED OR HIGH-POWER INFRARED LED FOR BEST RESULTS. FOR A FREE-SPACE RANGE OF UP TO 1,000 FEET (AT NIGHT), USE A LENS TO COLLIMATE THE LED BEAM. OR USE THIS CIRCUIT AS AN OPTICAL FIBER TRANSMITTER.

AM LIGHTWAVE RECEIVER

THIS RECEIVER WORKS BEST IN SUBDUED LIGHT OR AT NIGHT WHEN USED FOR FREE-SPACE COMMUNICATIONS. ALWAYS PLACE A SHIELD OVER THE DETECTOR IF SUNLIGHT OR BRIGHT ARTIFICIAL LIGHT IS PRESENT. AN INFRARED FILTER SHOULD BE USED FOR BEST RESULTS (DEVELOPED COLOR FILM WORKS WELL) UNLESS THE TRANSMITTER LED EMITS VISIBLE LIGHT.

<u>CAUTION</u>: THIS CIRCUIT CAN PRODUCE <u>LOUD</u> SOUNDS. DO <u>NOT</u> PLACE SPEAKER CLOSE TO YOUR EAR.

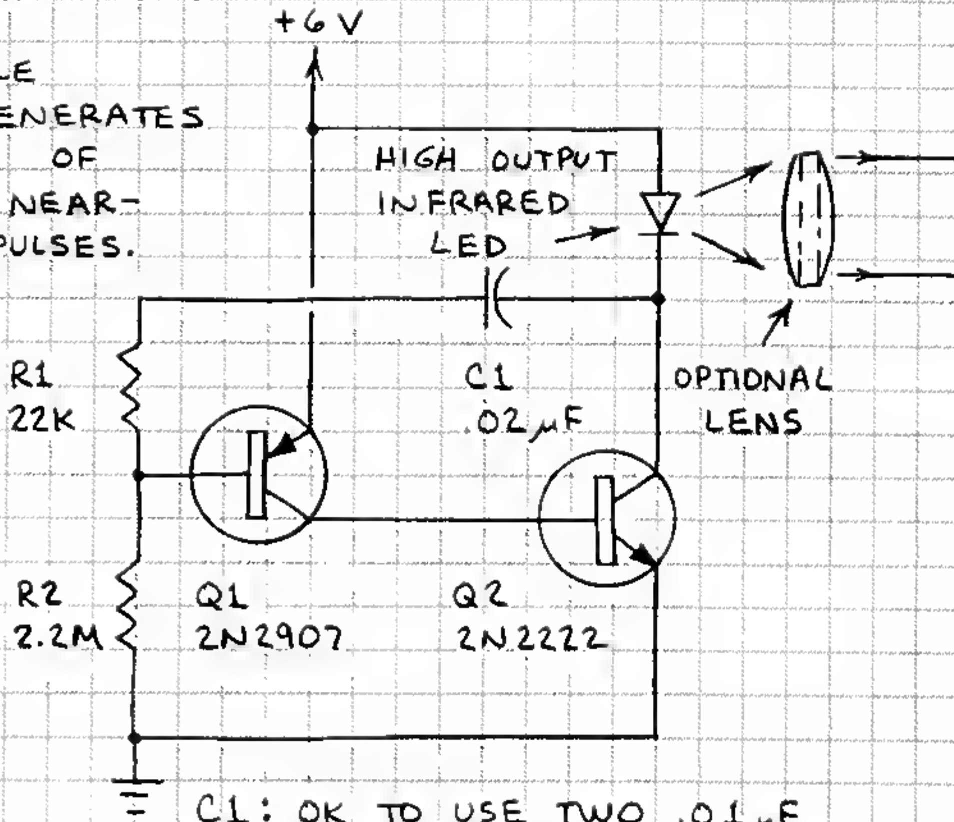


C2 PREVENTS OSCILLATION. KEEP LEADS TO BATTERY <u>SHORT</u>.

BREAK-BEAM DETECTION SYSTEM

TRANSMITTER

THIS SIMPLE CIRCUIT GENERATES A STREAM OF POWERFUL, NEAR-INFRARED PULSES.



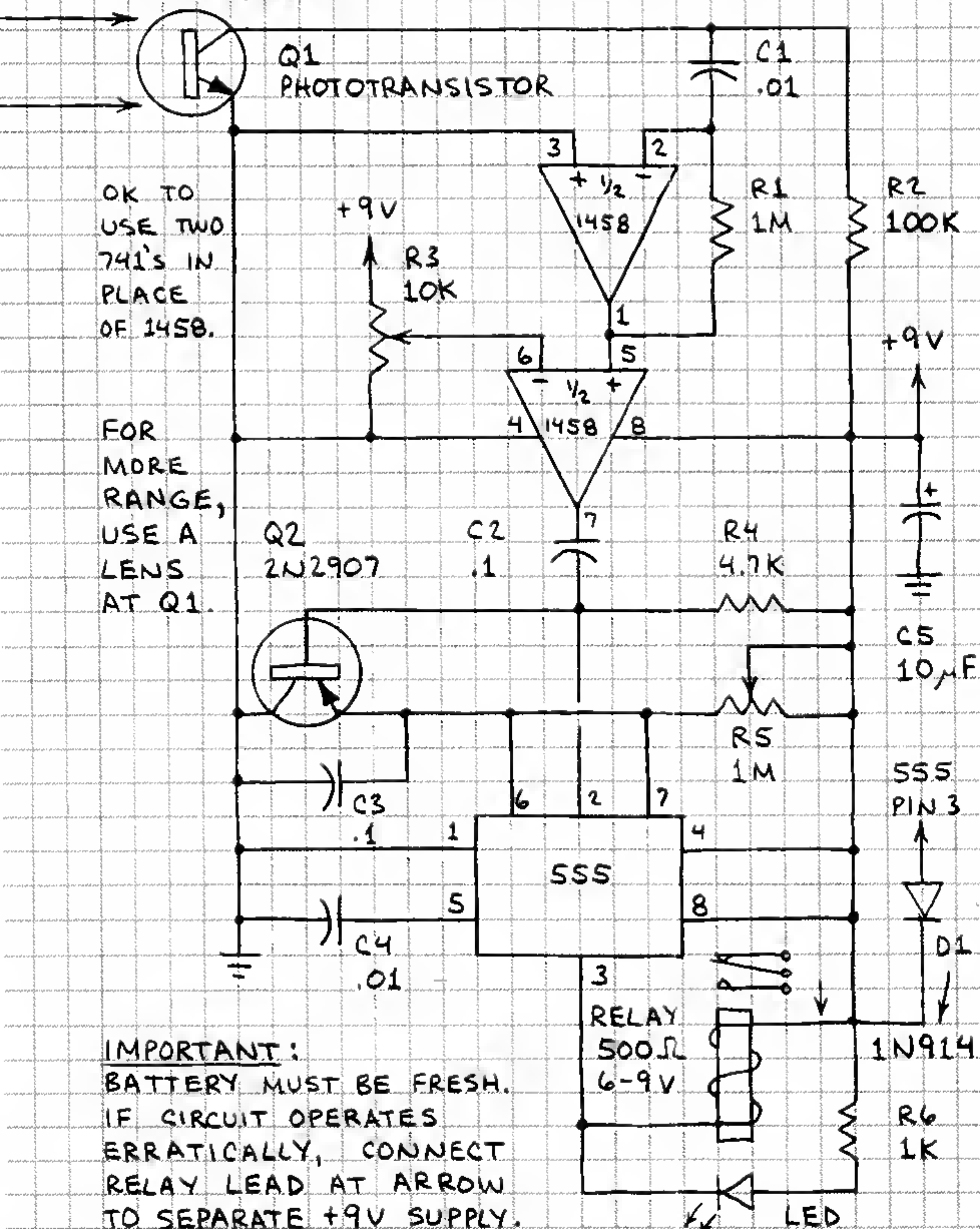
OUTPUT PULSE

C1: OK TO USE TWO .01μF CAPACITORS IN PARALLEL.

THIS SYSTEM IS A VERY SENSITIVE BREAK-BEAM DETECTOR. IT CAN BE USED TO DETECT OBJECTS OR PEOPLE THAT INTERRUPT THE TRANSMITTER BEAM. THE TRANSMITTER GENERATES ~240 PULSES PER SECOND, EACH 400μSEC IN DURATION WITH AN AMPLITUDE OF 400 mA. THE RECEIVER DETECTS THE NEAR INFRARED FROM THE TRANSMITTER BY MEANS OF PHOTOTRANSISTOR Q1. THE PHOTO-CURRENT FROM Q1 IS AMPLIFIED AND THEN SENT TO A THRESHOLD COMPARATOR. THE 555 FORMS A MISSING PULSE DETECTOR THAT ACTUATES THE RELAY AND LIGHTS THE LED WHEN THE INFRARED BEAM IS INTERRUPTED. RANGE WITHOUT LENSES IS AT LEAST SEVERAL FEET. USE LENSES FOR MUCH GREATER RANGE.

RECEIVER

SHIELD Q1 TO ELIMINATE AMBIENT LIGHT. ADJUST R3 TO SET THRESHOLD. ADJUST R5 TO ACHIEVE OPTIMUM RELAY OPERATION. ALWAYS TEST CIRCUIT IN SUBDUED LIGHT TO AVOID FALSE TRIGGERING.



OK TO USE TWO 741's IN PLACE OF 1458.

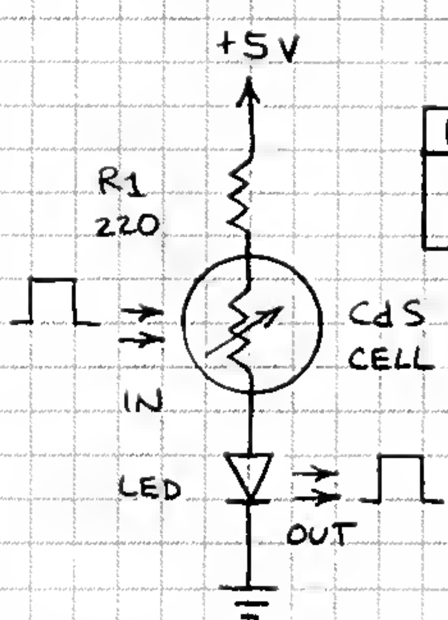
FOR MORE RANGE, USE A LENS AT Q1.

<u>IMPORTANT</u>:
BATTERY MUST BE FRESH. IF CIRCUIT OPERATES ERRATICALLY, CONNECT RELAY LEAD AT ARROW TO <u>SEPARATE</u> +9V SUPPLY.

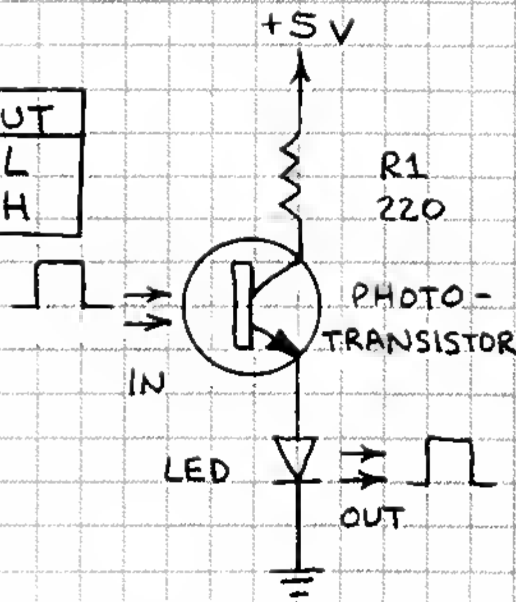
OPTOELECTRONIC LOGIC

THESE CIRCUITS CAN BE USED INDEPENDENTLY, IN CONJUNCTION WITH OPTOISOLATORS, OR AS OPTOELECTRONIC COMPUTING ELEMENTS.

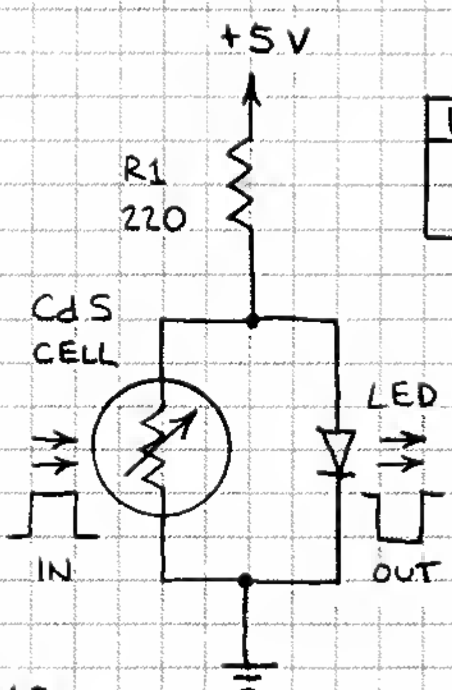
BUFFERS ("YES" CIRCUITS)



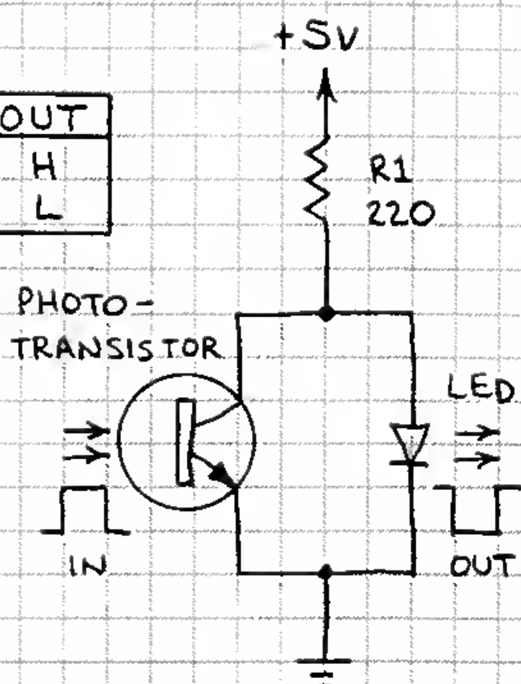
IN	OUT
L	L
H	H



INVERTERS ("NOT" CIRCUITS)

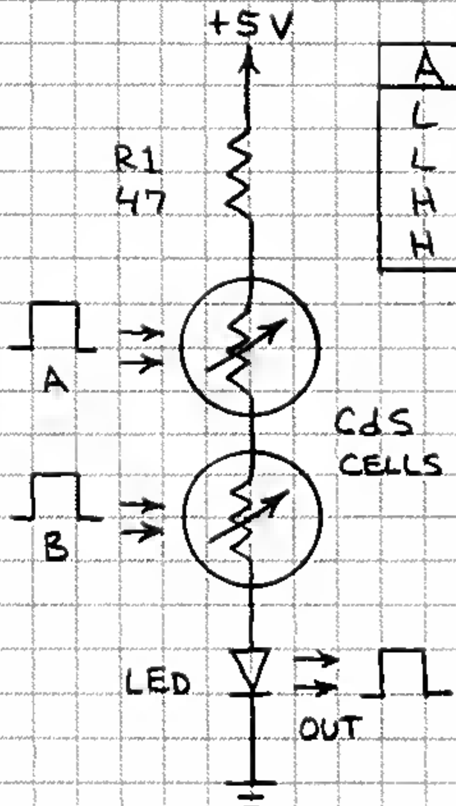


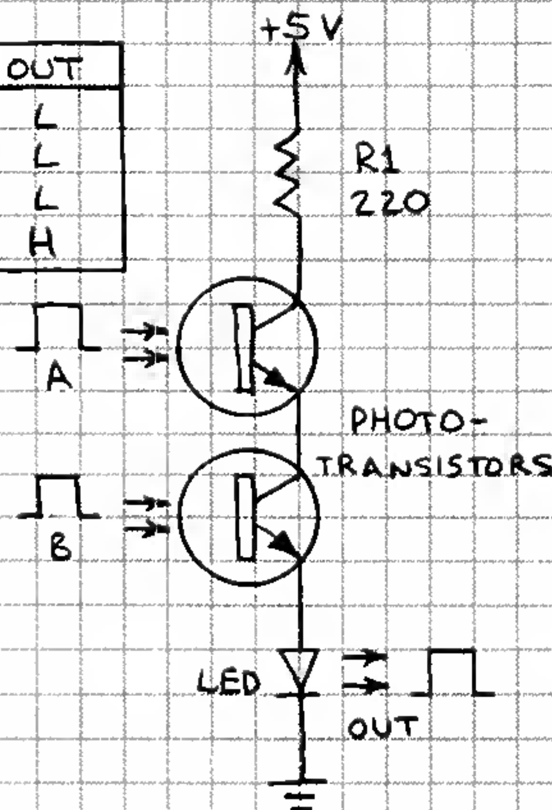
IN	OUT
L	H
H	L



AND CIRCUITS

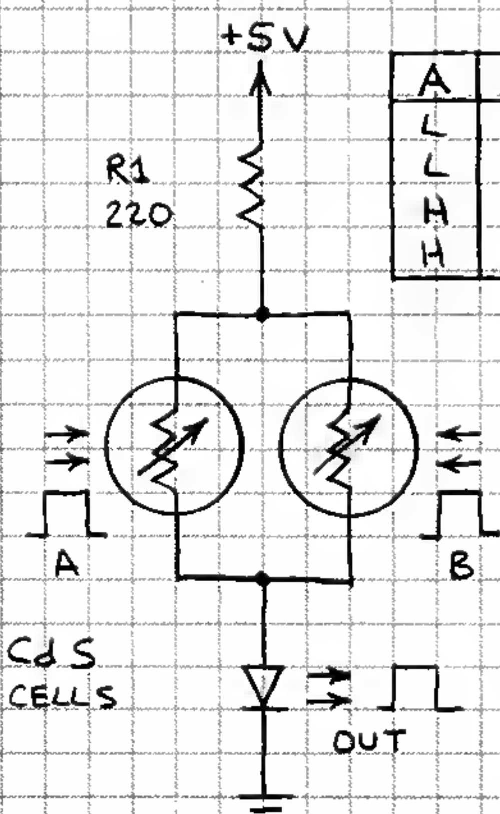
A	B	OUT
L	L	L
L	H	L
H	L	L
H	H	H

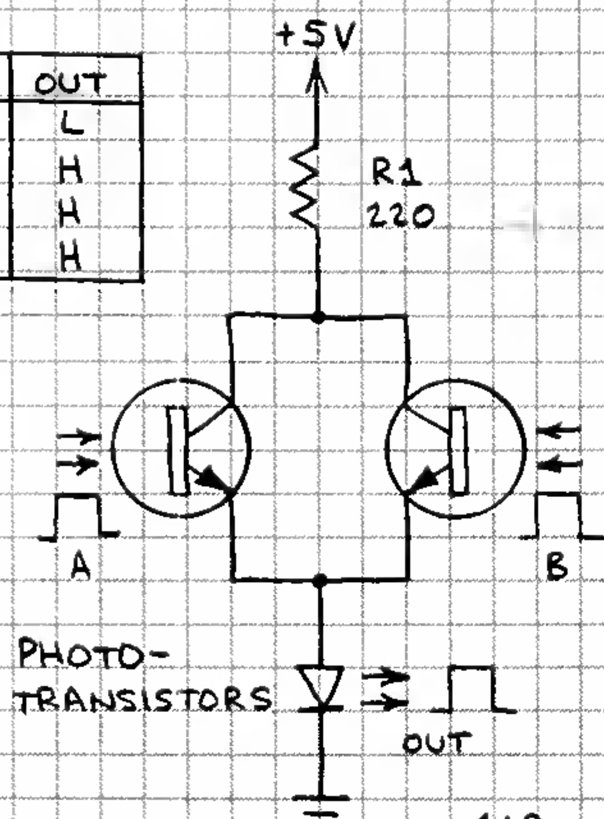




OR CIRCUITS

A	B	OUT
L	L	L
L	H	H
H	L	H
H	H	H



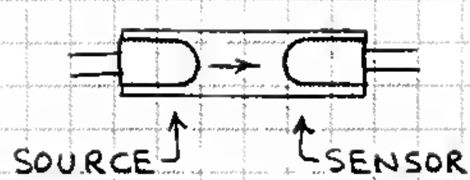


SOURCE / SENSOR PAIRS

SOURCE/SENSOR PAIRS ARE ALSO CALLED OPTO-ISOLATORS, OPTOCOUPLERS, PHOTO-ISOLATED COUPLERS, AND PHOTON ISOLATORS. THEY HAVE MANY IMPORTANT APPLICATIONS IN ELECTRONICS. THEY ARE PARTICULARLY IMPORTANT AT PROVIDING ELECTRICAL ISOLATION BETWEEN TWO SEPARATE CIRCUITS. MANY SOURCE-SENSOR COMBINATIONS CAN BE USED:

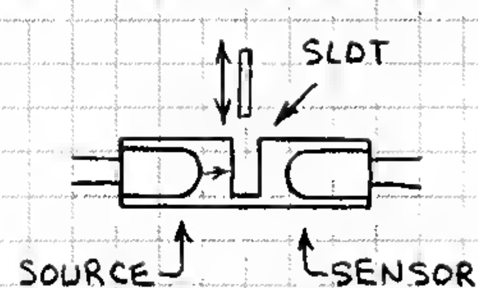
LED → PHOTOTRANSISTOR OR PHOTODIODE
LED → LIGHT-ACTIVATED SCR OR TRIAC
TUNGSTEN LAMP → PHOTORESISTOR
NEON LAMP → PHOTORESISTOR

CLOSED PAIR



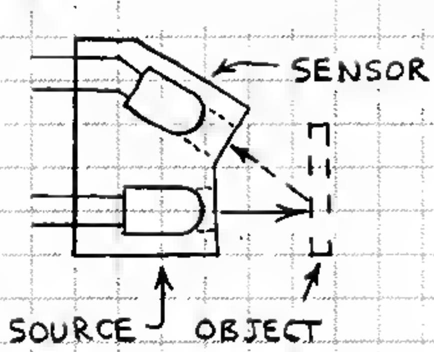
APPLICATIONS:
SOLID-STATE RELAY
ELECTRICAL ISOLATION
LEVEL CONVERSION

TRANSMISSION / SLOT PAIR



APPLICATIONS:
OBJECT DETECTION
LIMIT SWITCH
BOUNCE-FREE SWITCH
OPTO-POTENTIOMETER
VIBRATION DETECTOR

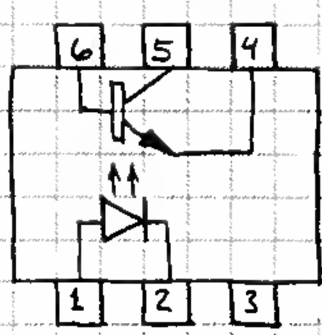
REFLECTIVE PAIR



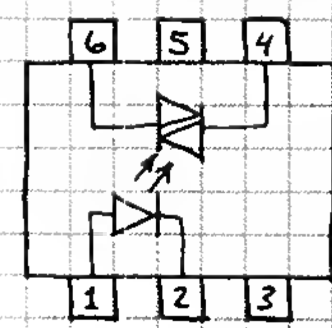
APPLICATIONS:
OBJECT DETECTION
LIMIT SWITCH
REFLECTANCE MONITOR
TACHOMETER
END-OF-TAPE DETECTOR
MOVEMENT DETECTOR

INTEGRATED SOURCE/SENSORS

MANY KINDS OF SOURCE/SENSOR PAIRS ARE AVAILABLE IN MINIATURE INTEGRATED CIRCUIT PACKAGES. HERE ARE TWO TYPICAL EXAMPLES:



LED/
PHOTOTRANSISTOR

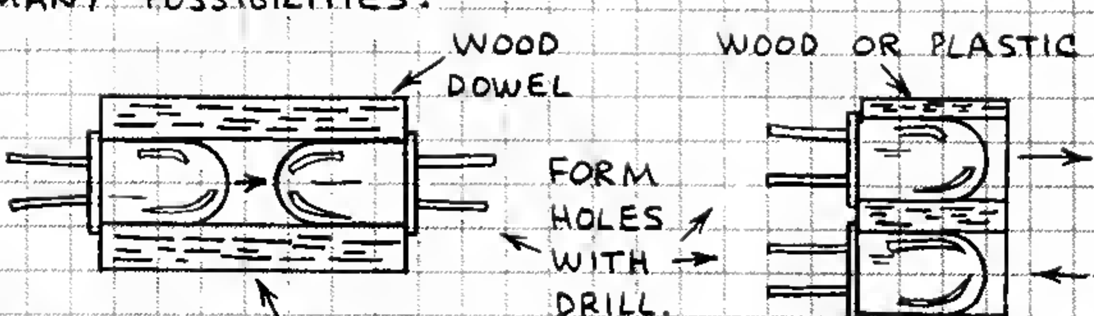


LED/
LIGHT-ACTIVATED TRIAC

DO-IT-YOURSELF SOURCE/SENSORS

SOURCE/SENSOR PAIRS CAN BE EASILY MADE FROM INDIVIDUAL COMPONENTS. FOR EXAMPLE, HERE IS A SIMPLE LED-PHOTOTRANSISTOR PAIR:

THE SOURCE AND SENSOR CAN BE INSTALLED IN WOOD OR PLASTIC STOCK. HERE ARE TWO OF MANY POSSIBILITIES:

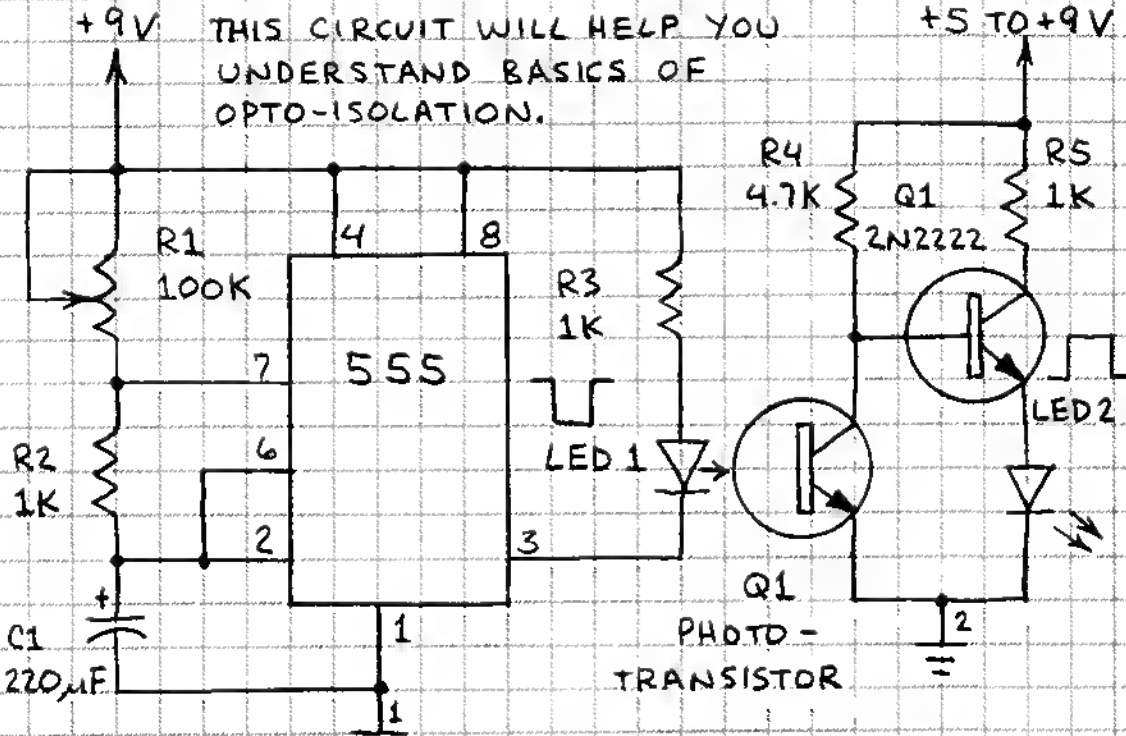


FORM SLOT HERE FOR TRANSMISSION SENSOR

REFLECTION SENSOR

DEMONSTRATION SOURCE/SENSOR

THIS CIRCUIT WILL HELP YOU UNDERSTAND BASICS OF OPTO-ISOLATION.



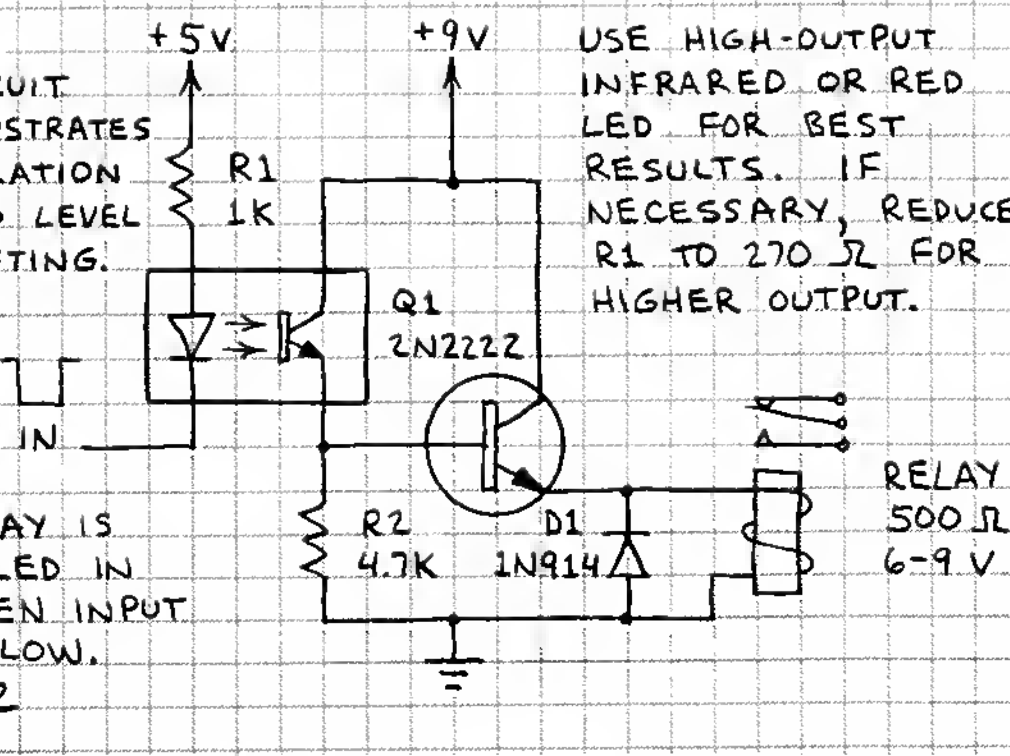
LED2: RED   LED1: HIGH OUTPUT RED

ADJUST R1 UNTIL LED1 FLASHES 1-2 TIMES PER SECOND. LED 2 WILL SWITCH OFF WHEN LED1 SWITCHES ON.

OPTOCOUPLER RELAY DRIVER

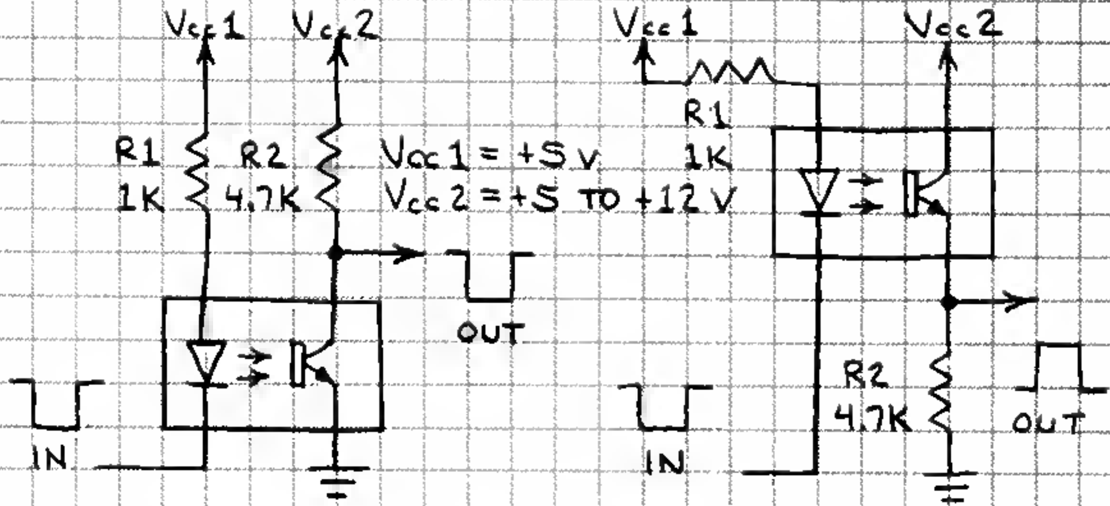
THIS CIRCUIT ILLUSTRATES ISOLATION AND LEVEL SHIFTING.

USE HIGH-OUTPUT INFRARED OR RED LED FOR BEST RESULTS. IF NECESSARY, REDUCE R1 TO 270 Ω FOR HIGHER OUTPUT.

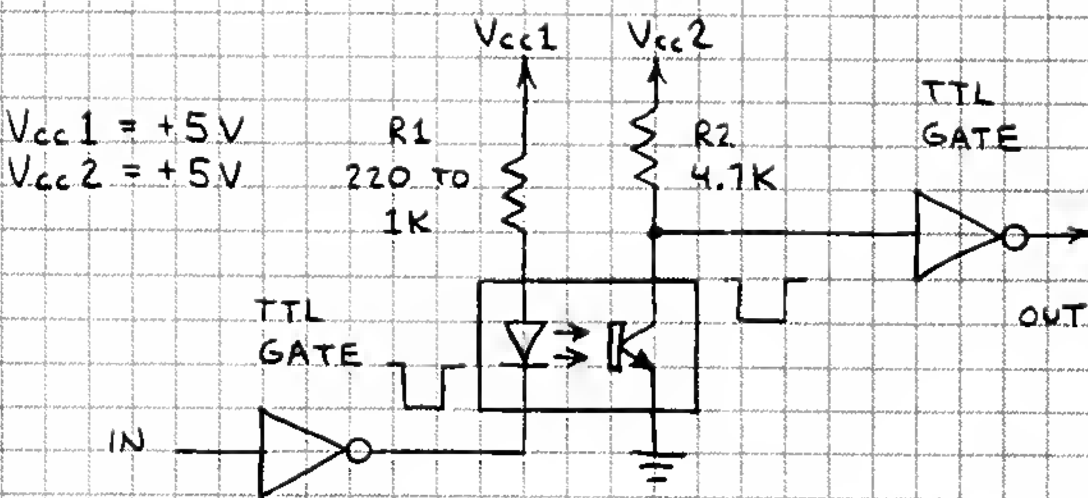


RELAY IS PULLED IN WHEN INPUT IS LOW.

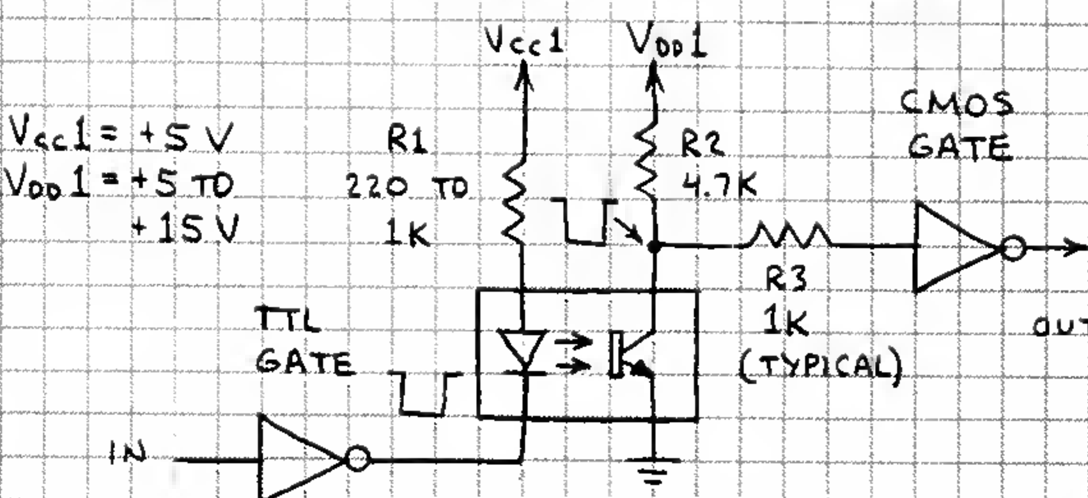
BASIC ISOLATORS / LEVEL SHIFTERS



TTL→TTL ISOLATOR

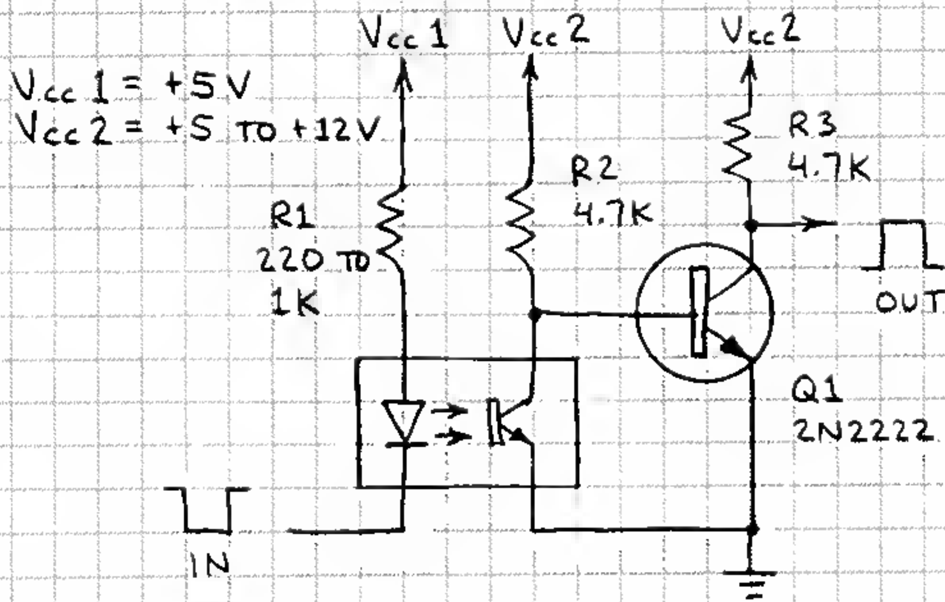


TTL→CMOS COUPLER / ISOLATOR

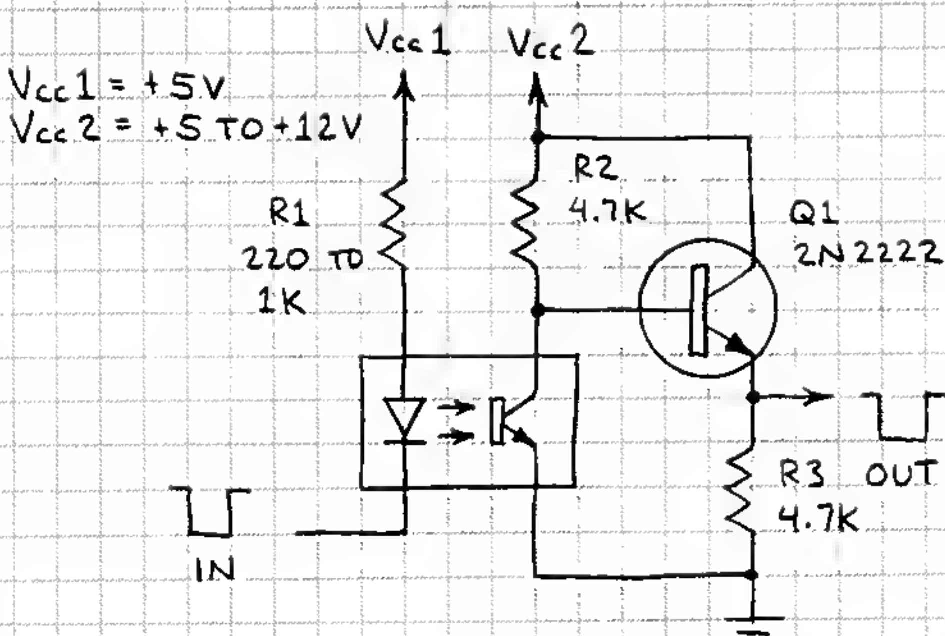


OPTOCOUPLER PLUS BOOSTER

INVERTED OUTPUT

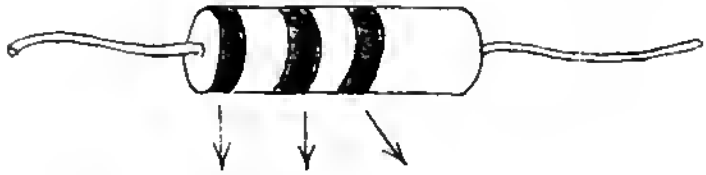


NON-INVERTED OUTPUT



THE BOOSTER TRANSISTOR (Q1) IN THESE CIRCUITS PROVIDES MORE POWER-HANDLING CAPABILITY THAN THE PHOTOTRANSISTORS IN MOST COMMERCIAL OPTOCOUPLERS. R3 CAN BE REPLACED BY A LOAD SUCH AS A RELAY.

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

The first RadioShack Engineer's Mini-Notebook was "555 Timer IC Circuits." This little book was an immediate success, and it was soon followed by "Op Amp Projects" and "Optoelectronics." This volume of the Engineer's Mini-Notebook Collection includes all three of these best-selling Engineer's Mini-Notebooks.

More than two dozen 555 timer circuits are featured in this volume, including tone generators, LED flashers, sound-effects circuits and a touch switch. Also included are more than 50 operational amplifier circuits, many with simple formulas to help modify them for special circuits of your own design. Finally, a wide range of optoelectronic circuits and projects are featured, including many LED circuits and various lightwave communication systems.

Forrest M. Mims III

Forrest M. Mims III has written dozens of books for RadioShack. He personally builds every circuit in his best-selling Engineer's Mini-Notebook series. He then uses a 0.7mm mechanical pencil to create pages for the finished book.

Building tiny instruments for model rockets, travel aids for the blind and high-power lasers is how Forrest got his start in electronics. When he's not writing RadioShack books, he writes magazine articles and teaches experimental science at the University of the Nations in Hawaii.

Forrest also does scientific studies of sunlight, the atmosphere, mosquitoes and bacteria using instruments he designs and makes. A simple instrument he developed to measure the ozone layer earned him a prestigious Rolex Award. NASA has sent Forrest and his instruments to several of the Western states and twice to Brazil to measure the effects of smoke from giant fires.

Forrest is a member of the Institute of Electrical and Electronics Engineers, the National Science Teachers Association and several scientific societies. He lives in Texas with his wife Minnie and their youngest daughter Sarah.

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