UNIVERSITY OF WOLLONGONG IN DUBAI

ECTE250

ENGINEERING DESIGN AND MANAGEMENT 2

Winter 2025 / Spring 2025

Practical Electronics 2

Outline

- Optoisolators and applications
- Reed relay
- Circuit to use Arduino digital output, optoisolator and reed relay with flyback diode
- Operational amplifiers and +/-15V DC power supply
- Basic operational amplifier building blocks for DC
  - Comparator circuits
  - Inverting op-amp and DC gain
  - The summing amplifier for DC voltages
  - Non-inverting op-amp and DC gain
  - Voltage follower (high input impedance, low output impedance)
  - Op-amp level shifter
- Oscillators, Clocks,
- heartbeat circuit design using NE555 timer Integrated Circuit
- Oscillators using Crystals
- Sensors Circuits

Optoisolators

- ECTE250 kit has an optoisolator chip in it.

- This is the 4N35 Optoisolator (referred to as the optocoupler in your Arduino projects book).

Optoisolator 4N35

GlobalOptoisolator™

VDE | UL | CSA | SETI | SEMKO | DEMKO | NEMKO | BABT

6-Pin DIP Optoisolators Transistor Output

The 4N35, 4N36 and 4N37 devices consist of a gallium arsenide infrared emitting diode optically coupled to a monolithic silicon phototransistor detector.

- Current Transfer Ratio — 100% Minimum @ Specified Conditions
- Guaranteed Switching Speeds
- Meets or Exceeds all JEDEC Registered Specifications
- ***To order devices that are tested and marked per VDE 0884 requirements, the suffix "V" must be included at end of part number. VDE 0884 is a test option.***

Applications

- General Purpose Switching Circuits
- Interfacing and coupling systems of different potentials and impedances
- Regulation Feedback Circuits
- Monitor & Detection Circuits
- Solid State Relays

MAXIMUM RATINGS (T_A = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
INPUT LED			
Reverse Voltage	V_R	6	Volts
Forward Current — Continuous	I_F	60	mA
LED Power Dissipation @ T_A = 25°C with Negligible Power in Output Detector Derate above 25°C	P_D	120 1.41	mW mW/°C
OUTPUT TRANSISTOR			
Collector–Emitter Voltage	V_{CEO}	30	Volts
Emitter–Base Voltage	V_{EBO}	7	Volts
Collector–Base Voltage	V_{CBO}	70	Volts
Collector Current — Continuous	I_C	150	mA

4N35*

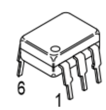
4N36

4N37

[CTR = 100% Min]

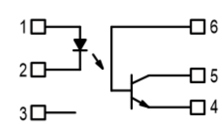
*Motorola Preferred Device

STYLE 1 PLASTIC



STANDARD THRU HOLE
CASE 730A–04

SCHEMATIC



PIN 1. LED ANODE
2. LED CATHODE
3. N.C.
4. EMITTER
5. COLLECTOR
6. BASE

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Optoisolator: Phototransistors

- Phototransistors are light-sensitive transistors.
- A common type of phototransistor resembles a bipolar transistor with its base lead removed and replaced with a light-sensitive surface area.
- When this surface area is kept dark, the device is off (practically no current flows through the collector-to-emitter region).
- **when the light-sensitive region is exposed to light, a small base current is generated that controls a much larger collector-to-emitter current.**
- phototransistors have maximum breakdown voltages and current and power dissipation ratings.
- **The collector current I_C through a phototransistor depends directly on the input radiation density, the dc current gain of the device, and the external base current**
- When a photo-transistor is used to control a collector-to-emitter current, a small amount of leakage current, called the *dark current* I_D, will flow through the device even when the device is kept in the dark. This current is usually insignificant (within the nA range).

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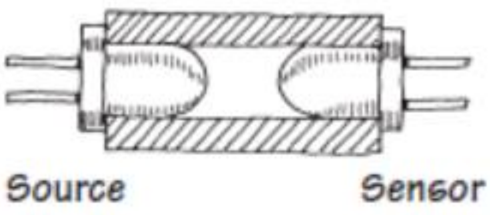
Optoisolator/Optocouplers

- Optoisolators/optocouplers are devices that interconnect two circuits by means of an optical interface.
- a typical optoisolator may consist of an LED and a photo-transistor enclosed in a light-tight container.
- Whenever the LED is supplied current, it emits photons that are detected by the phototransistor.
- optoisolators are used frequently to provide electrical isolation between two separate circuits.
- This means that ***one circuit can be used to control another circuit without undesirable changes in voltage and current that might occur if the two circuits were connected electrically***.

Optoisolator/Optocouplers

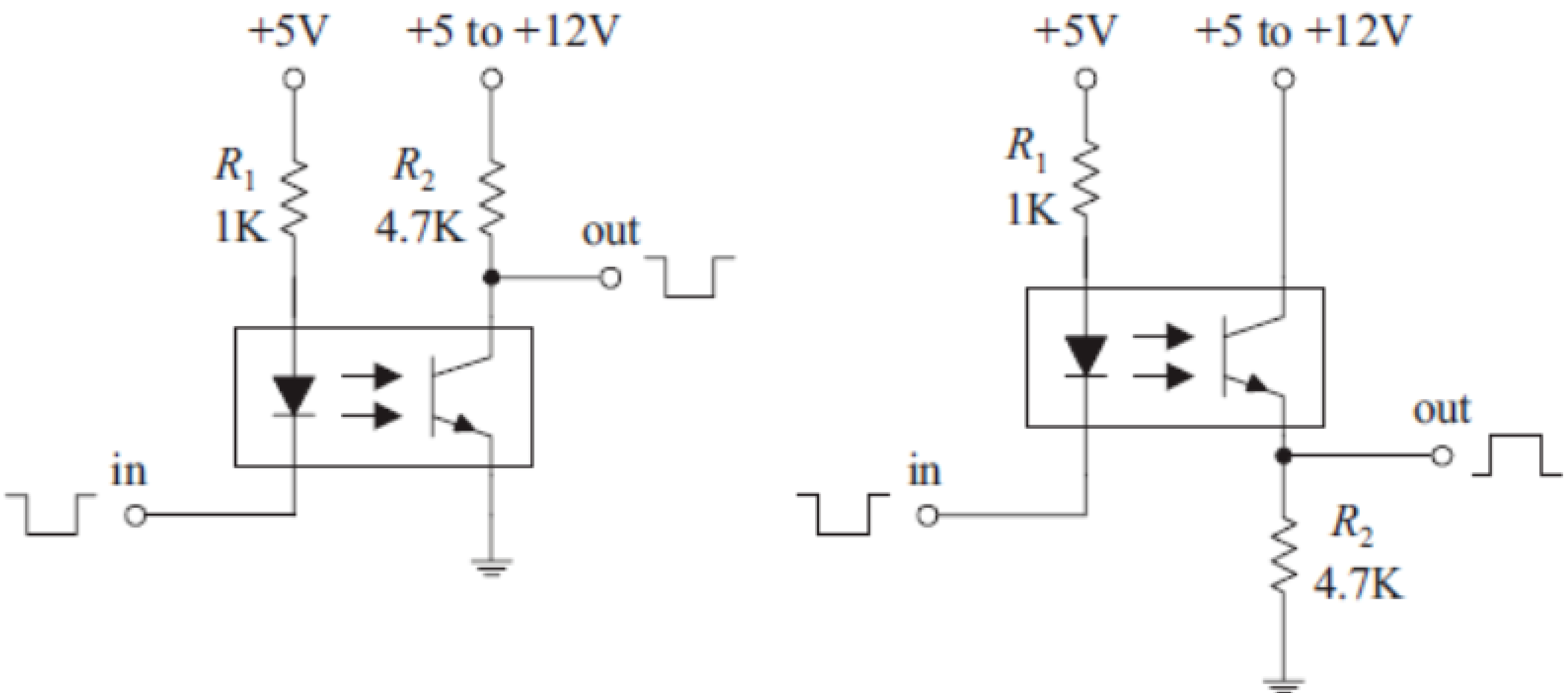
- Isolation couplers typically are enclosed in a dark container, with both source and sensor facing each other. In such an arrangement, the optoisolator is referred to as a *closed pair*
  - closed pairs are also used for level conversions and solid-state relaying.

(a) Closed pair



Optoisolator/Optocouplers

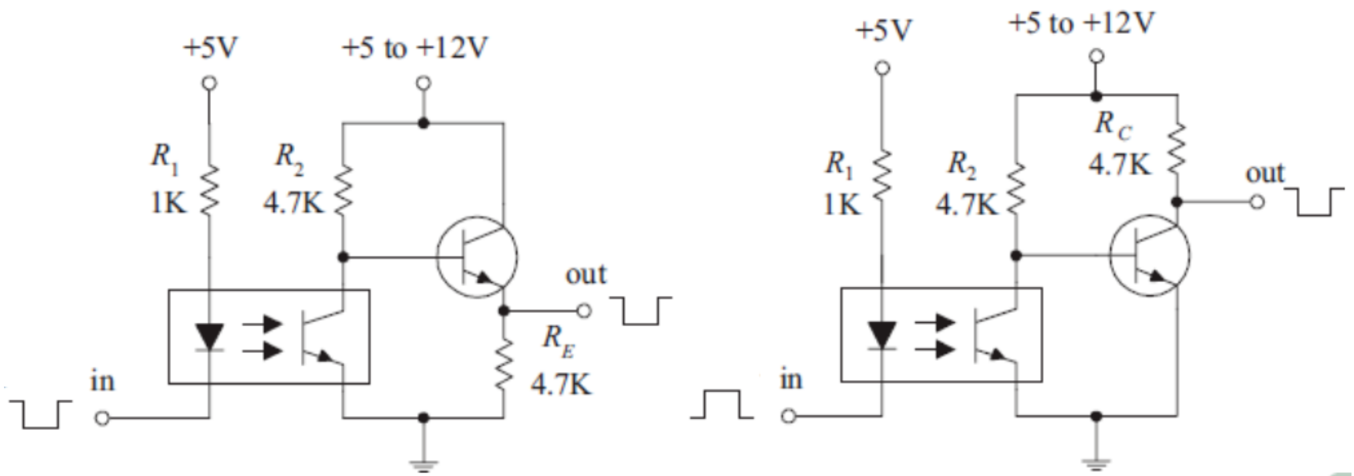
- Applications: Level shifting



Optoisolator/optocouplers

Applications: Optoisolator with amplifier

- In both these circuits a diode/phototransistor optoisolator is used to provide electrical isolation between the source circuit and the sensor circuit, as well as providing a dc level shift in the output.



- In the left circuit, the output is not inverted. The output in the right circuit is inverted.

www.youtube.com/watch?app=desktop&v=2BdevOmN-Zk

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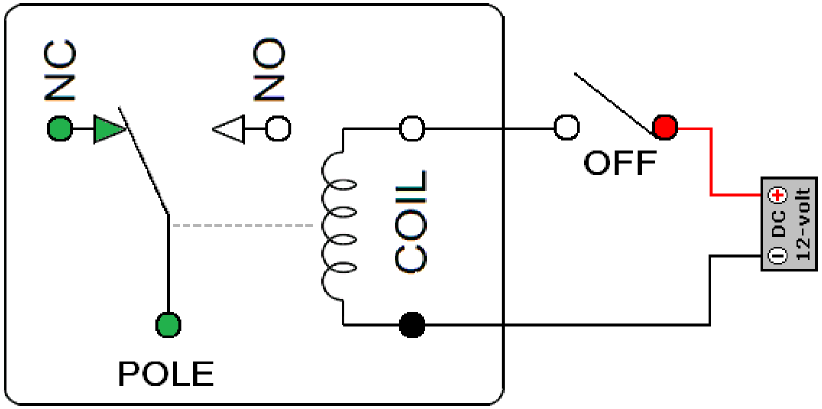
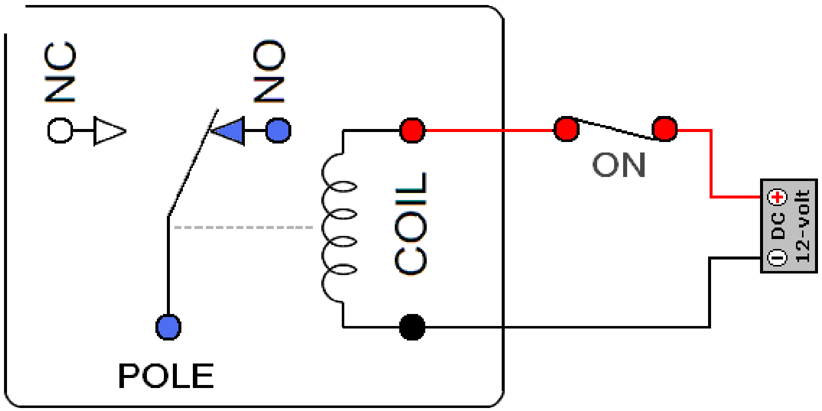
Reed Relay

- A Reed Relay is an electromechanical switch operated my a magnetic field





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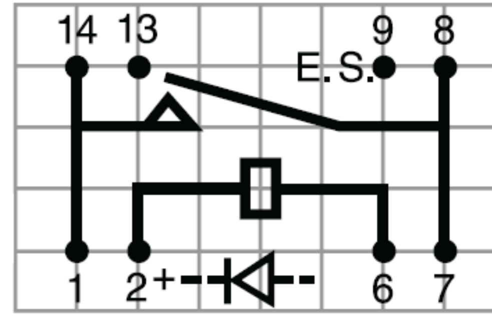
SPTS DIL Reed Relay

- Single Pole Single Throw Reed Relay in a Dual Inline Package



Reed Relays
DIL Packaged > HE700

Littelfuse
Expertise Applied | Answers Delivered

HE700 Miniature Dual In-line Reed Relay

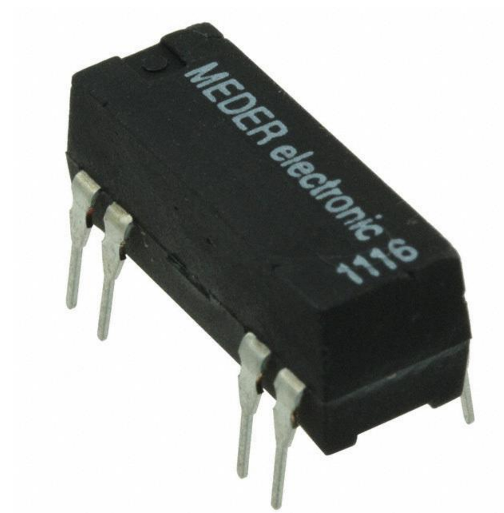
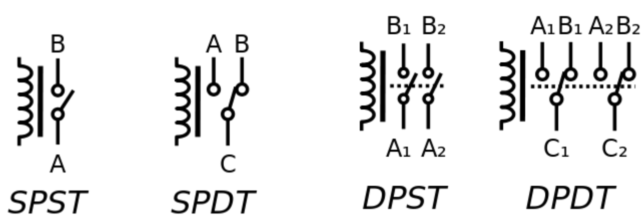


Table 3: Coil Characteristics @ 25°C

Contact Form	Electrical and Operating Characteristics	Dimensions	Part Number	Nominal Coil Voltage Vdc	Coil Resistance ±10% Ohms	Must Operate Vdc	Must Release Vdc	Maximum Coil Voltage Vdc	Top View 2.54mm (0.1") Grid Dot on Case: Pin 1 Numbers not printed on case.
1A SPST-NO	See Table 2 Column 1	Figure 1	HE721A0500	5	500	3.75	0.5	12	
			HE721A1200	12	1000	8.0	1.0	31	
			HE721A2400	24	2150	16.0	2.0	46	

- Other Types of Relay



DIL Reed Relay

- An optoisolator could be coupled with a Reed Relay, which has a Normally Open contact which can be used to drive another circuit in your system as an on/off mechanism

- That's why a reed relay is included in ECTE250 part list

- But it does come at a power cost, so use only when needed (same with the optoisolators)!

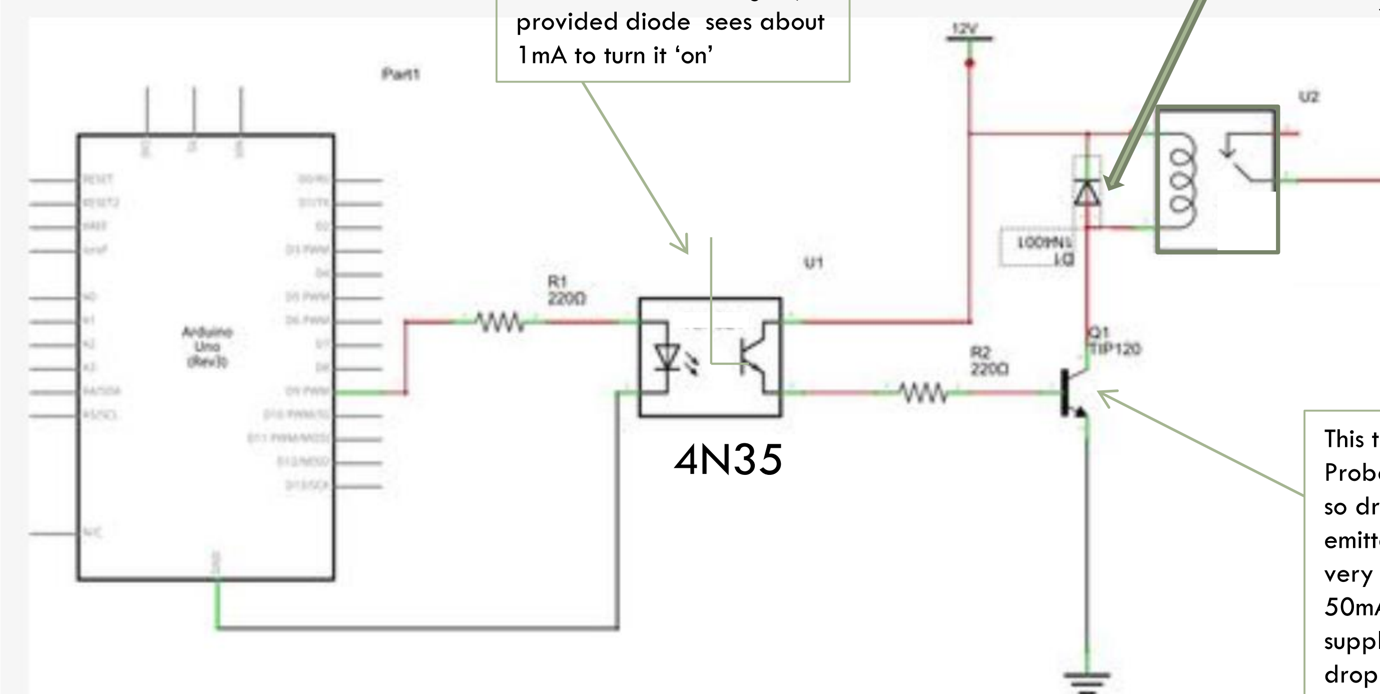
- Also since the relay is an inductor it's a good idea to use a flyback diode so that any sudden switching changes in the inductor will be removed through the diode

Optoisolator & Relay w/ Arduino

- Can use a 1N4007 as a flyback diode

Relay
SPST (we have a 500 ohm, 5V Reed Relay, so lower voltage may be warranted)

Leave base unconnected
The diode provides the base current which puts transistor in active region, provided diode sees about 1mA to turn it 'on'



4N35

This transistor will Probably be in saturation, so drop across Collector emitter is 0.2 volts, with a very high base current (20-50mA) and most of the supply voltage of 12 volts is dropped across the relay coil (use a resistor if coil not rated for more than 5 volts)

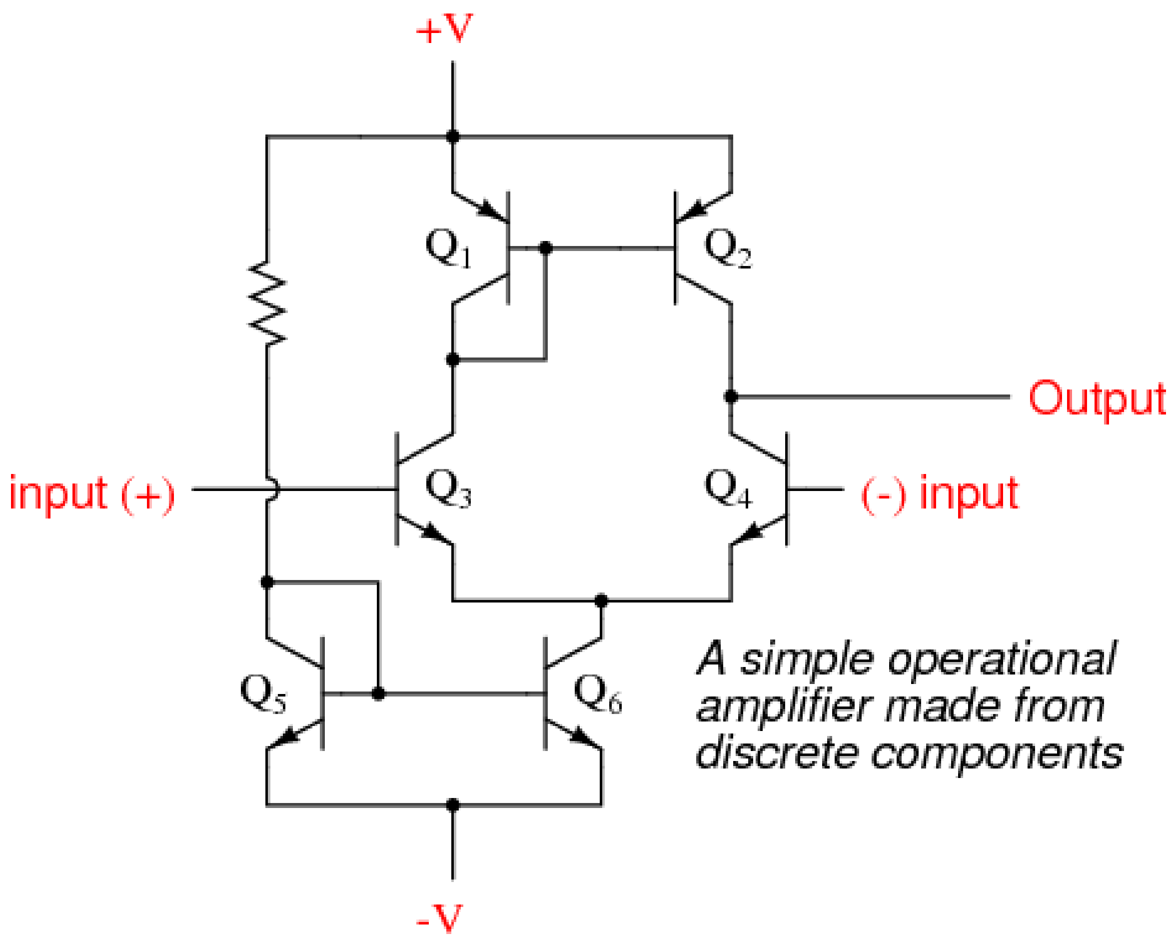
The Operational Amplifier

- Now there is a device which we will concentrate on using in DC circuits as building block circuits
- ECTE212 (Electronics) will look at the workings of an op-amp and the AC and DC analysis and will also talk about how these circuits work and what a virtual earth, and a virtual short circuit are and what open-loop gain is for an op-amp (though these are all discussed in the 'practical electronics for inventors' text if you are interested)
- We will just look at how to use these different op-amp circuits as components in larger modules for different applications inside ECTE250 projects

The Operational Amplifier

- Often Abbreviated : Op-Amp
- Actually it is composed of multiple transistor circuits
- But (for ECTE250) we don’t care…
- Because to use an Operational amplifier does not require an in depth knowledge of the internal circuitry
- Instead we need to remember a few simple rules!
- There are Unipolar (require GND & Vcc) and Bipolar Op-Amp (require -Vcc +Vcc).

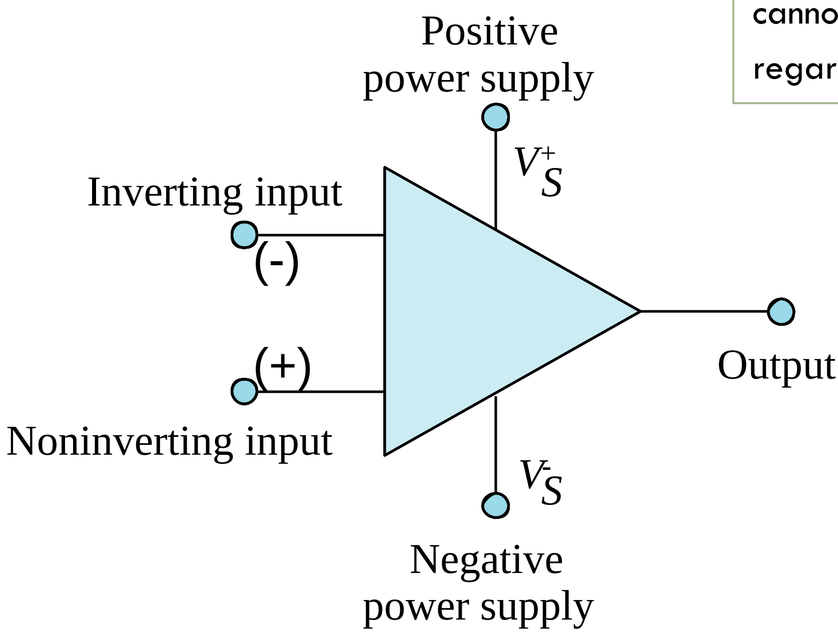
The Operational Amplifier



A simple operational amplifier made from discrete components

The Operational Amplifier

Important Notes: If you don't connect the power rails For your op-amp it will not perform the indicated circuit functions – these voltages are often not drawn on a schematic because they are assumed present, also output voltages cannot be more positive or more negative than the supply rails regardless of any DC gain of the circuit!



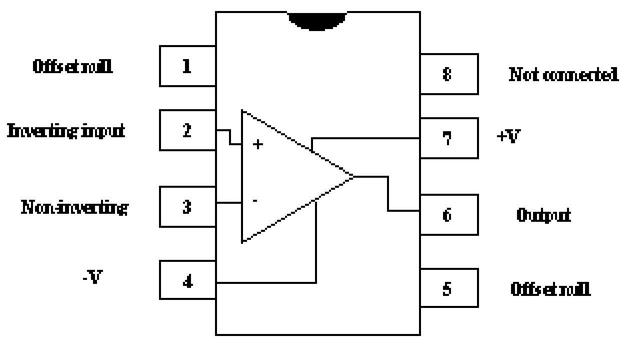
Simplified circuit symbol

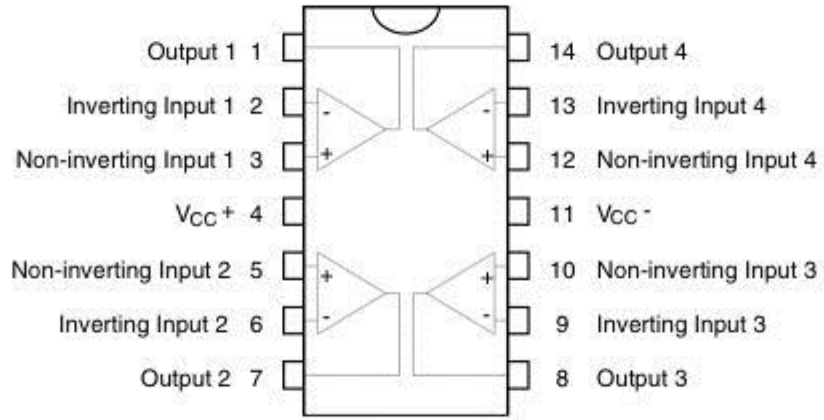
$$V_S^- < V_{out} < V_S^+$$

Example: $+V_S$ is +15 volts,
$-V_S$ is -15 volts
Then V_{out} is somewhere
Between the power
Supply extremes!

The Operational Amplifier

- For ECTE250 you have TL071 and TL074 (Quad Pack)





TL071 and TL074

MOTOROLA

Low Noise, JFET Input Operational Amplifiers

These low noise JFET input operational amplifiers combine two state–of–the–art analog technologies on a single monolithic integrated circuit. Each internally compensated operational amplifier has well matched high voltage JFET input device for low input offset voltage. The BIFET technology provides wide bandwidths and fast slew rates with low input bias currents, input offset currents, and supply currents. Moreover, the devices exhibit low noise and low harmonic distortion, making them ideal for use in high fidelity audio amplifier applications.

These devices are available in single, dual and quad operational amplifiers which are pin–compatible with the industry standard MC1741, MC1458, and the MC3403/LM324 bipolar products.

- Low Input Noise Voltage: 18 nV/$\sqrt{\text{Hz}}$ Typ
- Low Harmonic Distortion: 0.01% Typ
- Low Input Bias and Offset Currents
- High Input Impedance: 10^{12} Ω Typ
- High Slew Rate: 13 V/µs Typ
- Wide Gain Bandwidth: 4.0 MHz Typ
- Low Supply Current: 1.4 mA per Amp

TL071C,AC
TL072C,AC
TL074C,AC

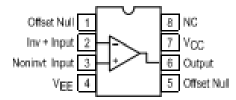
LOW NOISE, JFET INPUT OPERATIONAL AMPLIFIERS

SEMICONDUCTOR TECHNICAL DATA

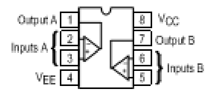
P SUFFIX
PLASTIC PACKAGE
CASE 626

D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO–8)

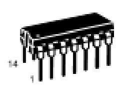
PIN CONNECTIONS



TL071 (Top View)

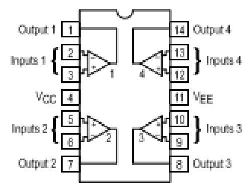


TL072 (Top View)



N SUFFIX
PLASTIC PACKAGE
CASE 646
(TL074 Only)

PIN CONNECTIONS



TL074 (Top View)

ORDERING INFORMATION

Op Amp Function	Device	Operating Temperature Range	Package
Single	TL071CD	T_A = 0° to +70°C	SO–8
	TL071ACP		Plastic DIP
Dual	TL072CD	T_A = 0° to +70°C	SO–8
	TL072ACP		Plastic DIP
Quad	TL074CN, ACN	T_A = 0° to +70°C	Plastic DIP

 Rev 1

TL074
TL074A - TL074B

LOW NOISE J-FET QUAD OPERATIONAL AMPLIFIERS

- WIDE COMMON-MODE (UP TO V_{CC}^+) AND DIFFERENTIAL VOLTAGE RANGE
- LOW INPUT BIAS AND OFFSET CURRENT
- LOW NOISE e_n = 15nV/√Hz (typ)
- OUTPUT SHORT-CIRCUIT PROTECTION
- HIGH INPUT IMPEDANCE J–FET INPUT STAGE
- LOW HARMONIC DISTORTION : 0.01% (typ)
- INTERNAL FREQUENCY COMPENSATION
- LATCH UP FREE OPERATION
- HIGH SLEW RATE : 13V/µs (typ)

N
DIP14
(Plastic Package)

D
SO14
(Plastic Micropackage)

DESCRIPTION

The TL074, TL074A and TL074B are high speed J–FET input quad operational amplifiers incorporating well matched, high voltage J–FET and bipolar transistors in a monolithic integrated circuit.

The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient.

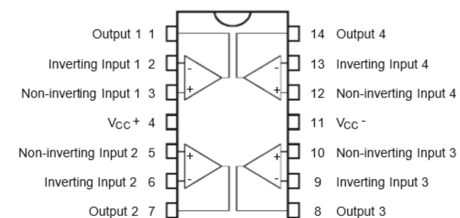
ORDER CODE

Part Number	Temperature Range	Package N	Package D
TL074M/AM/BM	-55°C, +125°C	•	•
TL074I/AI/BI	-40°C, +105°C	•	•
TL074C/AC/BC	0°C, +70°C	•	•

Example : TL074IN

N = Dual in Line Package (DIP)
D = Small Outline Package (SO) - also available in Tape & Reel (DT)

PIN CONNECTIONS (top view)



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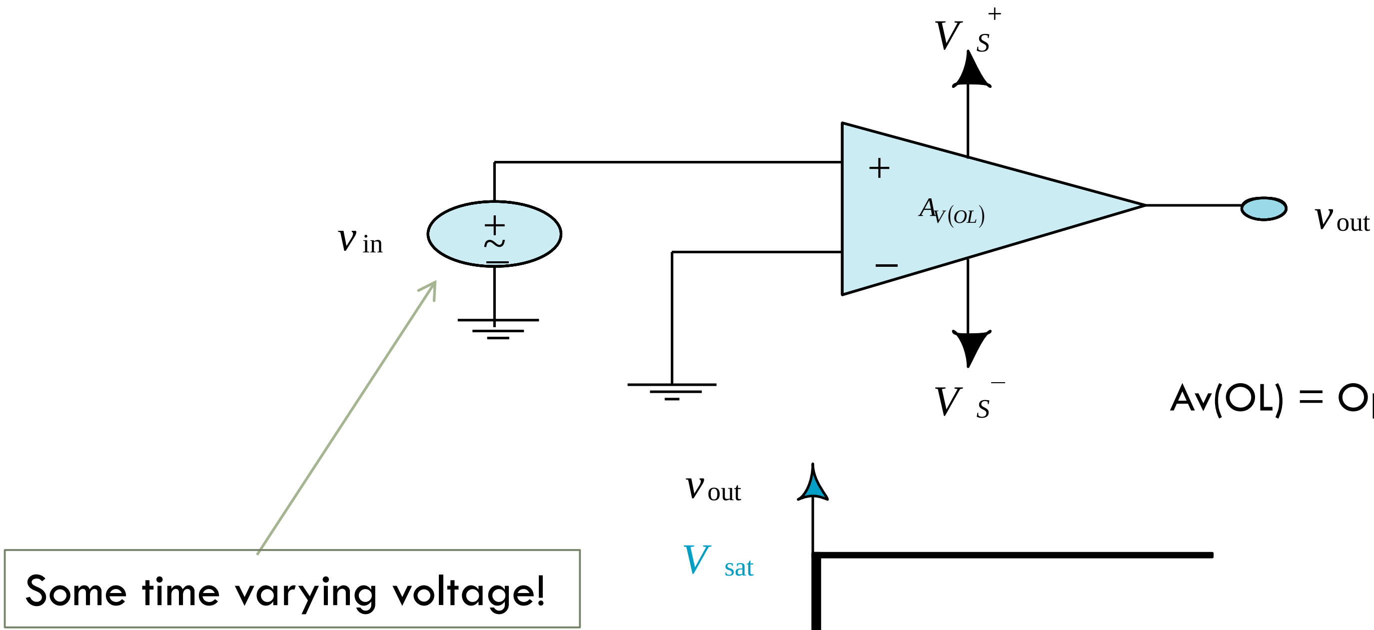
Basic Op-Amp Circuits

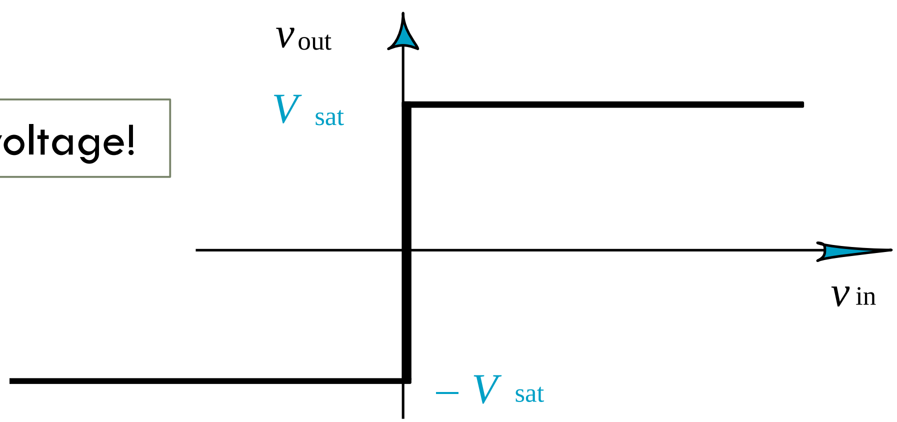
- Here are a set of commonly needed building blocks for op-amp circuits (here we will only look at DC circuits involving op-amps)

The Operational Amplifier

- Zero-Crossing Comparator

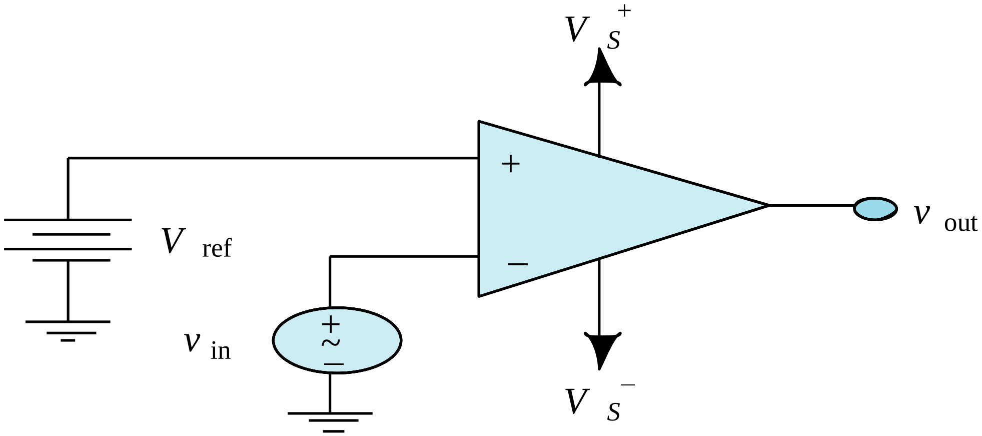


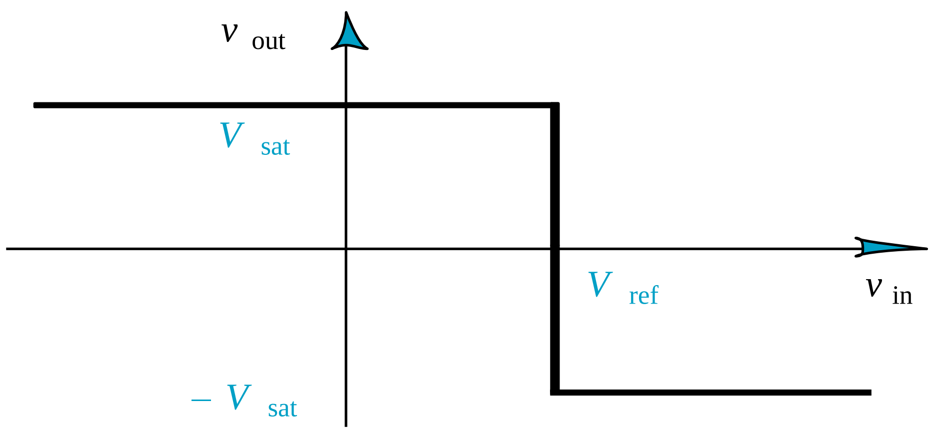
Av(OL) = Open Loop Voltage Gain



The Operational Amplifier

- Inverting comparator with offset





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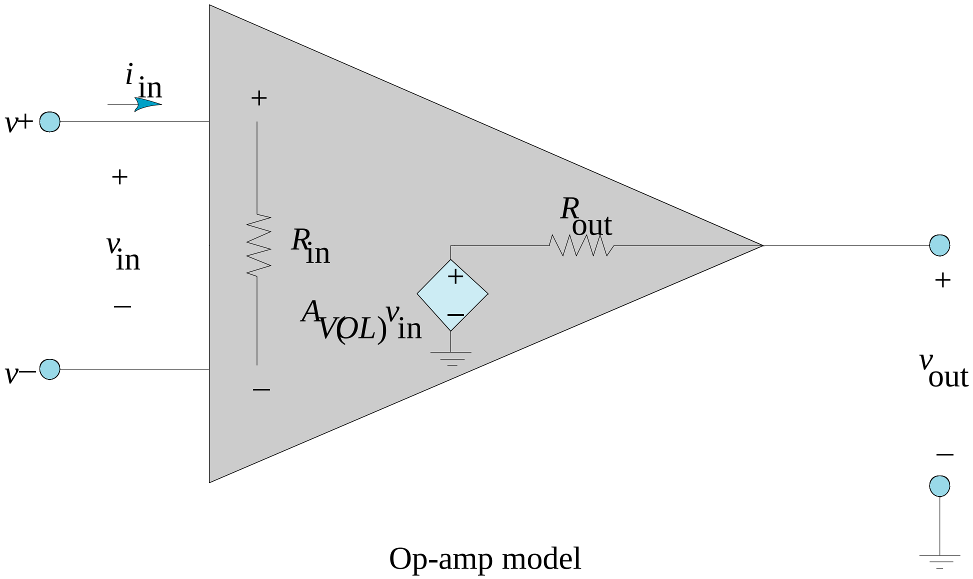
The Operational Amplifier

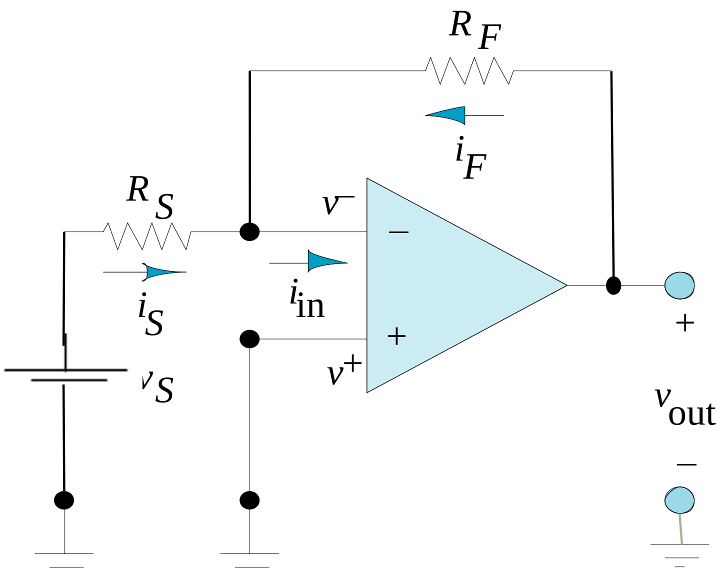
- Operational amplifiers are almost always used with negative feedback, in which part of the output signal is returned to the input in opposition to the source signal.
- An ideal Op-Amp has
  - Infinite voltage gain
  - Infinite input impedance
  - Zero output impedance
  - Infinite bandwidth
  - Zero input offset voltage
    - i.e., exactly zero out if zero in.



Op-amp model

The Operational Amplifier

- In a negative feedback system, the ideal op-amp output voltage attains the value needed to **force the differential input voltage and input current to zero.**

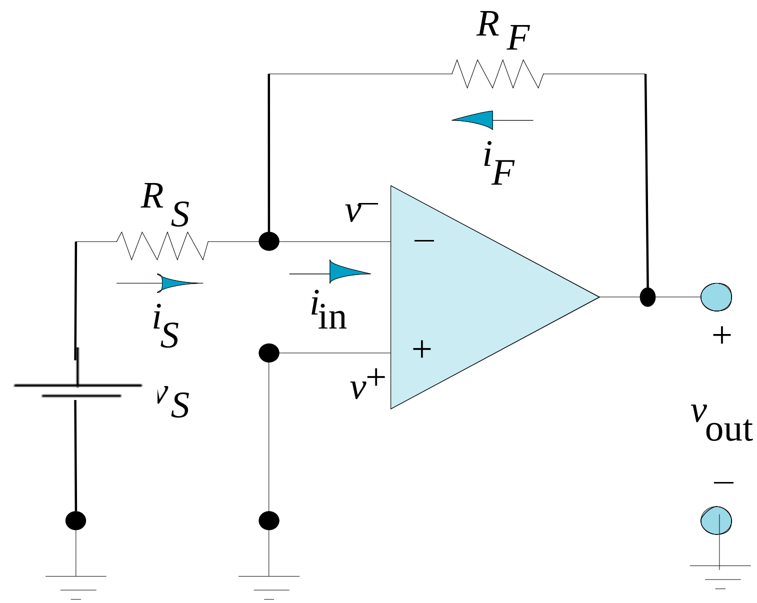


- Part of the output is returned to the input
- The feedback signal opposes the input source

The Operational Amplifier

- Inverting Amplifier
  - Relationship for this circuit is:

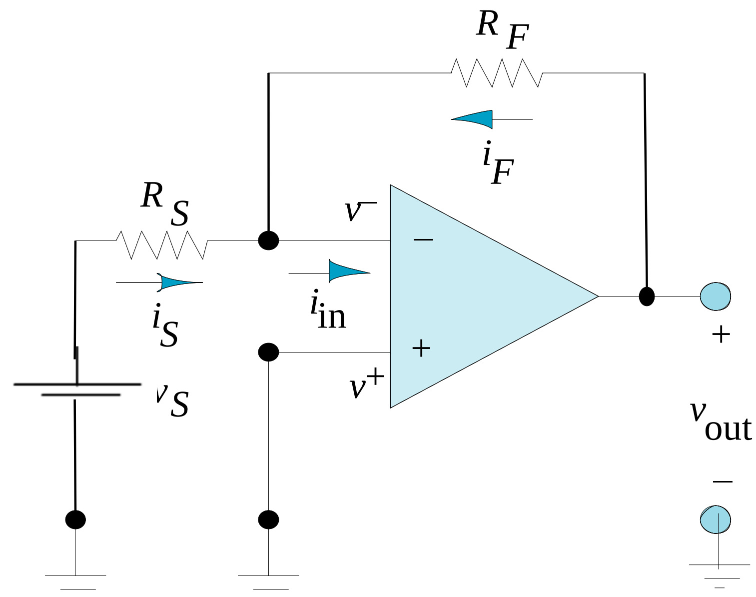
$$\frac{v_{out}}{v_S} = -\frac{R_F}{R_S} = Gain = A_v$$



The Operational Amplifier

- Inverting Amplifier Example 1

If the input voltage, v_S, is 2 volts DC and the supply rails are +15 volts and -15 volts respectively (not Shown) what is the output Voltage v_{out} equal to when R_S=10 kΩ and R_F=20 kΩ?



$$\frac{v_{out}}{v_S} = -\frac{R_F}{R_S} = Gain = A_v = -\frac{20000 \quad \Omega}{10000 \quad \Omega} = -2$$

$$\therefore v_{out} = -2v_S = -2 \times 2 = -4 \quad volts$$

Notice that this voltage is still between the voltage supply rails of the op-amp and is inverted (opposite polarity) to the input voltage

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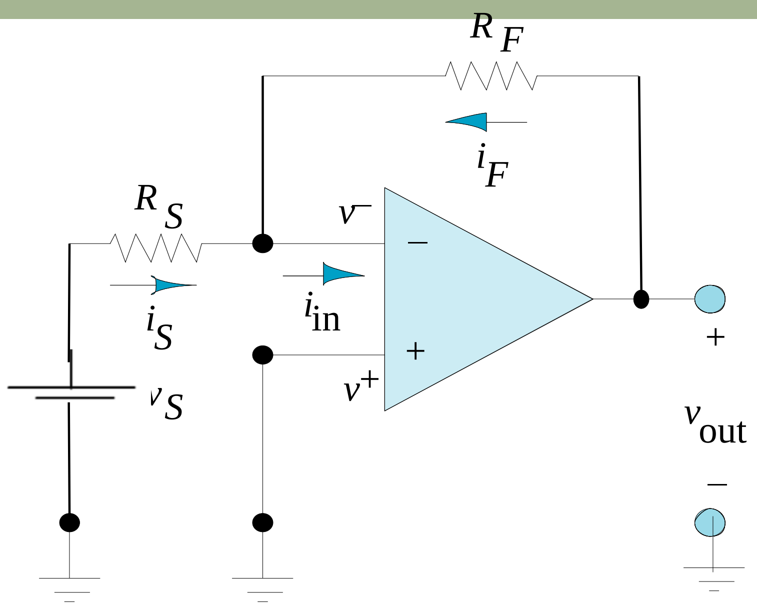
The Operational Amplifier

- Inverting Amplifier Example 2

If the input voltage, v_S, is -3.333 Volts DC and the supply rails are +15 volts and -15 volts respectively (not Shown) what is the output Voltage v_{out} equal to when RS=1 kOhms and RF=3 kOhms?



$$\frac{v_{out}}{v_S} = -\frac{R_F}{R_S} = Gain = A_v = -\frac{3000 \quad \Omega}{1000 \quad \Omega} = -3$$

$$\therefore v_{out} = -3v_S = -3\times\left(\frac{-10}{3}\right) = +10 \quad volts$$

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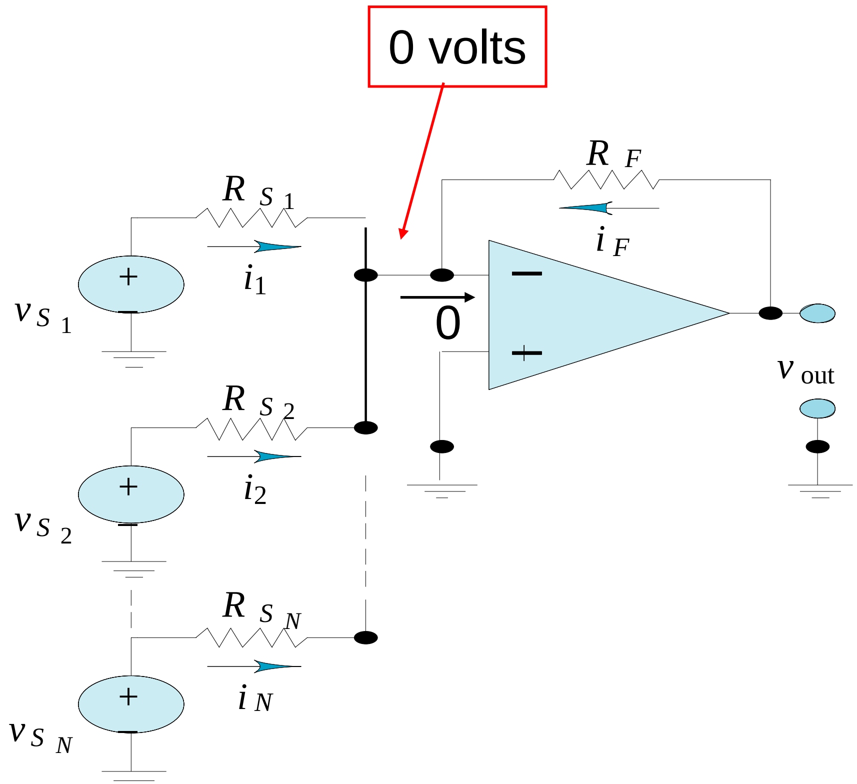
The Operational Amplifier

- The Summing Amplifier

$$v_{out} = -R_F \cdot \left(\frac{v_{S1}}{R_{S1}} + \frac{v_{S2}}{R_{S2}} + \cdots + \frac{v_{SN}}{R_{SN}} \right)$$



- If we allow all the input resistors to be the same

$$R_{S1} = R_{S2} = \cdots = R_{SN} = R_S$$

- Then

$$\boxed{v_{out} = -\frac{R_F}{R_S}\left(v_{S1} + v_{S2} + \cdots + v_{SN}\right)}$$

That is the SUM!

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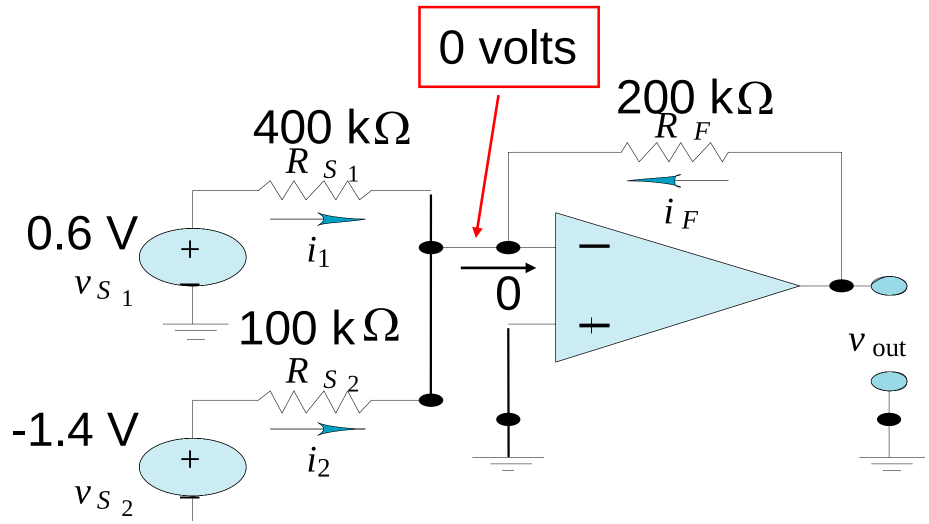
The Operational Amplifier

- The Summing Amplifier Example

- If v_{s1}=+0.6 V and v_{s2} = -1.4 V, with R_{S1} = 400kΩ and R_{S2}= 100kΩ, and R_F=200kΩ, determine the output voltage.



$$v_{out} = -R_F \cdot \left(\frac{v_{S1}}{R_{S1}} + \frac{v_{S2}}{R_{S2}} \right)$$

$$v_{out} = -(200 \quad k\Omega) \cdot \left(\frac{0.6 \quad volts}{400 \quad k\Omega} + \frac{-1.4 \quad volts}{100 \quad k\Omega} \right)$$

$$= -\left(\frac{200}{100}\right) \cdot \left(\frac{6}{40} - \frac{7 \times 8}{5 \times 8} \right) = -2 \cdot \left(-\frac{50}{40} \right) = +2.5 \quad volts$$

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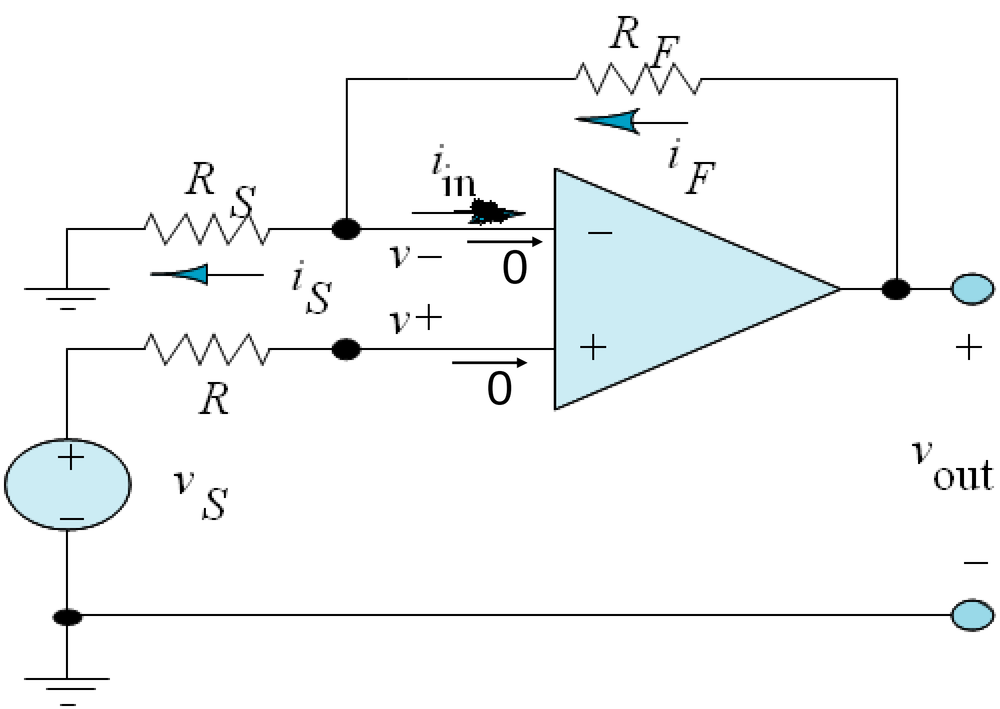
The Operational Amplifier

- Non-Inverting Amplifier

$$v_{out} = \frac{v_S}{R_S}(R_F + R_S) = \left(1 + \frac{R_F}{R_S}\right) \cdot v_S$$



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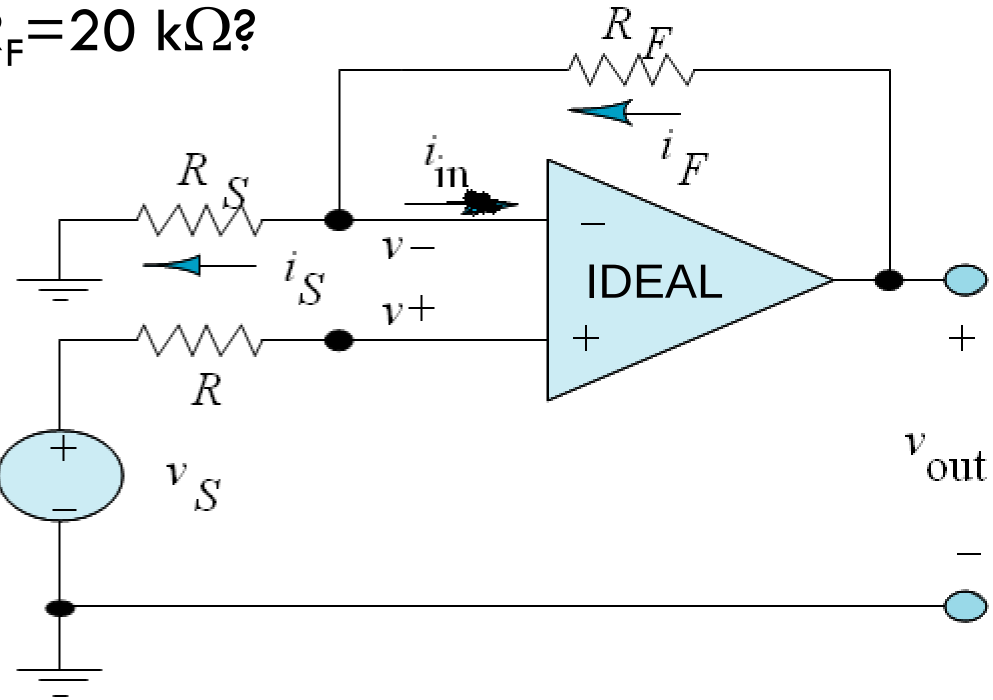
The Operational Amplifier

- Non-Inverting Amplifier Example
- If the input voltage, v_S, is 2 volts DC and the supply rails are +15 volts and -15 volts respectively (not Shown) what is the output Voltage v_{out} equal to when R_S=10 kΩ and R_F=20 kΩ?



$$v_{out} = \left(1 + \frac{R_F}{R_S}\right) \cdot v_S$$

$$= \left(1 + \frac{20}{10}\right) \cdot (2) = +6\, Volts$$

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The Operational Amplifier

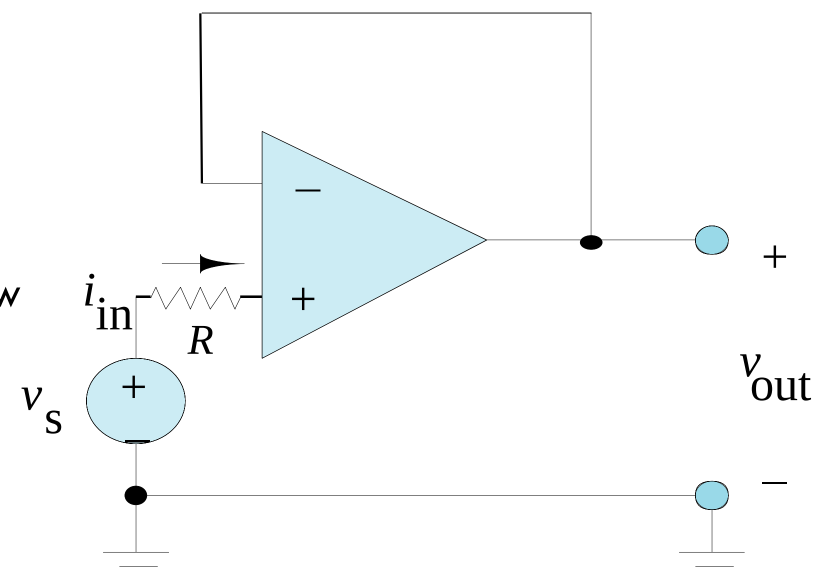
Voltage Follower or Buffer

- Since the op-amp is ideal there is zero current into the +ve terminal and no need for R, which can be modeled as the internal resistance of the source, v_s
- The virtual short circuit between the +ve and –ve terminals means that:

$$v_{out} = v_S \qquad 0$$

- And we have a high resistance input with low resistance output with the same voltage at the output as the source: hence the term **voltage follower**!

Note: The op-amp in the TL071 and Opamps in the TL074 have very high Open loop gains, typically 100000



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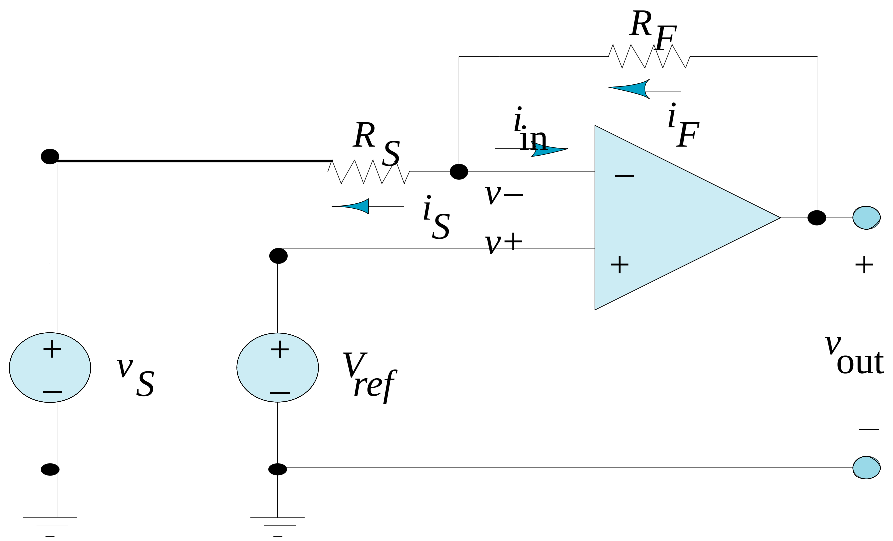
The Operational Amplifier

- Level Shifter
- This provides a method to Shift the DC level of a circuit
- Needed , for example, to remove DC!



$$v_{out} = -\frac{R_F}{R_S} v_S + \left(1 + \frac{R_F}{R_S}\right) V_{ref}$$

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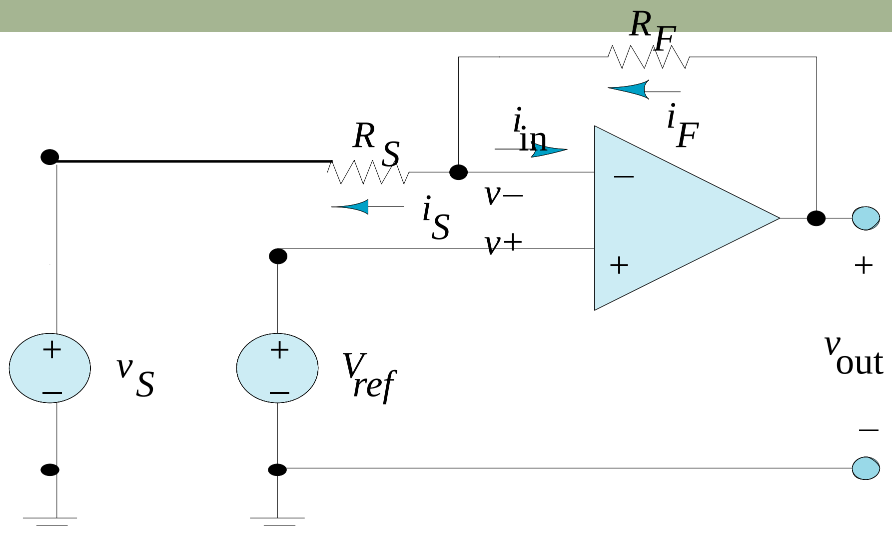
The Operational Amplifier

- Level Shifter Example
- Given

$$v_S = 1.8 + 0.1\cos(\omega t);$$
$$R_S = 10k \quad \Omega;$$
$$R_F = 220k \quad \Omega;$$

- Find: V_{ref} to remove the DC bias



$$v_{out} = -\frac{R_F}{R_S}\left[1.8 + 0.1\cos(\omega t)\right] + \left(1 + \frac{R_F}{R_S}\right)V_{ref} = -\frac{R_F}{R_S}0.1\cos(\omega t) - \frac{R_F}{R_S}(1.8) + \left(1 + \frac{R_F}{R_S}\right)V_{ref}$$

Removing the sinusoid and setting the DC component to equal zero:

$$-\frac{R_F}{R_S}(1.8) + \left(1 + \frac{R_F}{R_S}\right)V_{ref} = 0 \quad \Rightarrow \quad V_{ref} = 1.72 \quad V$$

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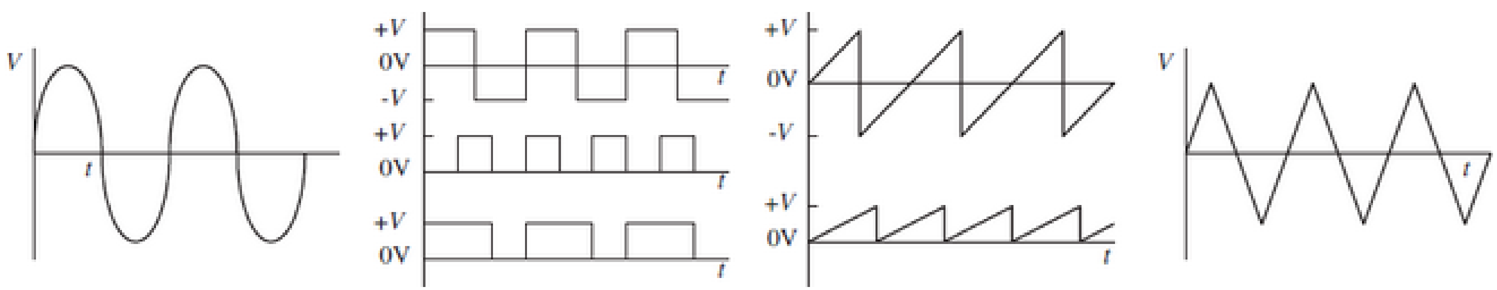
Oscillators

- Within practically every electronic instrument there is an oscillator of some sort.
- The task of the oscillator is to generate a repetitive **waveform** of desired **shape**, **frequency**, and **amplitude** that can be used to **drive other circuits.**
- Depending on the application, the driven circuit(s) may require either a pulsed, sinusoidal, square, sawtooth, or triangular waveform:



Oscillators & Clocks

- In digital electronics, square wave oscillators, called *clocks,* are used to drive bits of information through logic gates and flip-flops at a rate of speed determined by the frequency of the clock.

- Your state machine is a digital circuit, so it needs a clock.

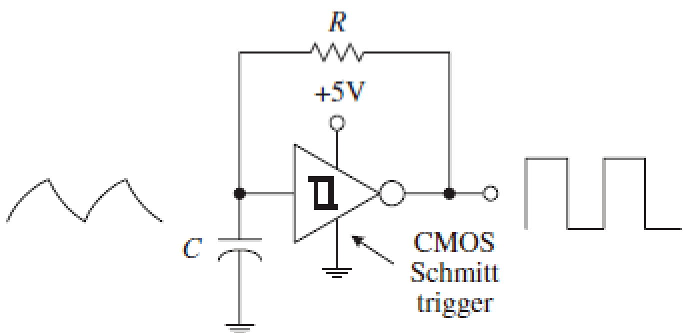
- There are many different designs for clocks, we are only going to look at the ones that are relevant to ECTE250 projects
  - see chapter 10 of practical electronics for inventors for circuits using op-amps

Oscillators & Clocks

Some simple circuits useful in ECTE250.

the 74HC132 Schmitt trigger NAND gate (available for ECTE250) can be turned into an inverter by connecting both inputs together.

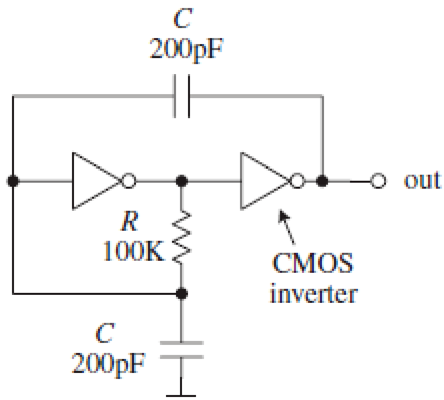
Digital oscillator
(using a Schmitt trigger inverter)



The on/off times are determined by the positive- and negative-going threshold voltages and the *RC* time constant.

$$f = \frac{1}{0.8RC}$$

Digital oscillator (using inverters)



Inverters with voltages from 4 to 18Volts. The Frequency of oscillation is given by:

$$f = \frac{1}{4RC\ln 2} = \frac{1}{2.8RC}$$

Oscillators & Clocks: The NE555

- This chip allows us to generate signals using capacitors and resistors

- We have this in the ECTE250 part list and we specify that a heartbeat signal is required using a NE555 timer

The NE555 Timer

- Note its maximum operating frequency is higher than 500kHz, more than required for an ECTE250 heartbeat!

Philips Semiconductors Linear Products — Product specification

Timer — **NE/SA/SE555/SE555C**

DESCRIPTION

The 555 monolithic timing circuit is a highly stable controller capable of producing accurate time delays, or oscillation. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200mA.

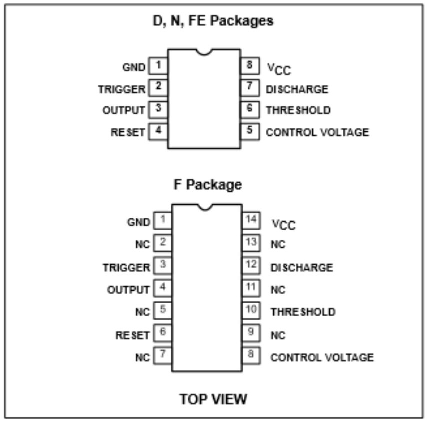
FEATURES

- Turn-off time less than 2μs
- Max. operating frequency greater than 500kHz
- Timing from microseconds to hours
- Operates in both astable and monostable modes
- High output current
- Adjustable duty cycle
- TTL compatible
- Temperature stability of 0.005% per °C

APPLICATIONS

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation

PIN CONFIGURATIONS



ORDERING INFORMATION

DESCRIPTION	TEMPERATURE RANGE	ORDER CODE	DWG #
8-Pin Plastic Small Outline (SO) Package	0 to +70°C	NE555D	0174C
8-Pin Plastic Dual In-Line Package (DIP)	0 to +70°C	NE555N	0404B
8-Pin Plastic Dual In-Line Package (DIP)	-40°C to +85°C	SA555N	0404B
8-Pin Plastic Small Outline (SO) Package	-40°C to +85°C	SA555D	0174C
8-Pin Hermetic Ceramic Dual In-Line Package (CERDIP)	-55°C to +125°C	SE555CFE	
8-Pin Plastic Dual In-Line Package (DIP)	-55°C to +125°C	SE555CN	0404B
14-Pin Plastic Dual In-Line Package (DIP)	-55°C to +125°C	SE555N	0405B
8-Pin Hermetic Cerdip	-55°C to +125°C	SE555FE	
14-Pin Ceramic Dual In-Line Package (CERDIP)	0 to +70°C	NE555F	0581B
14-Pin Ceramic Dual In-Line Package (CERDIP)	-55°C to +125°C	SE555F	0581B
14-Pin Ceramic Dual In-Line Package (CERDIP)	-55°C to +125°C	SE555CF	0581B

The NE555 Timer

- The *555* timer IC is an incredibly useful precision timer that can act as either a timer or an oscillator.

- In **timer** mode—better known as *monostable mode*—the *555* simply acts as a "one-shot" timer
  - when a trigger voltage is applied to its trigger lead, the chip's output goes from low to high for a duration set by an external *RC* circuit

- In **oscillator** mode—better known as *astable mode*—the *555* acts as a rectangular-wave generator whose output waveform (low duration, high duration, frequency, etc.) can be adjusted by means of two external *RC* charge/discharge circuits.

The NE555 Timer

- The 555 timer IC is easy to use
- The 555 timer IC is inexpensive
- The 555 timer IC can be used in an amazing number of applications:
  - possible to create digital clock waveform generators
  - LED and lamp flasher circuits
  - tone-generator circuits (sirens, metronomes, etc.)
  - one-shot timer circuits
  - bounce-free switches
  - triangular-waveform generators
  - frequency dividers

The NE555 Timer: Astable Mode

Astable Mode: how to generate a rectangular waveform with different duty cycles

This is a simplified block diagram of a 555 IC in Astable configuration:

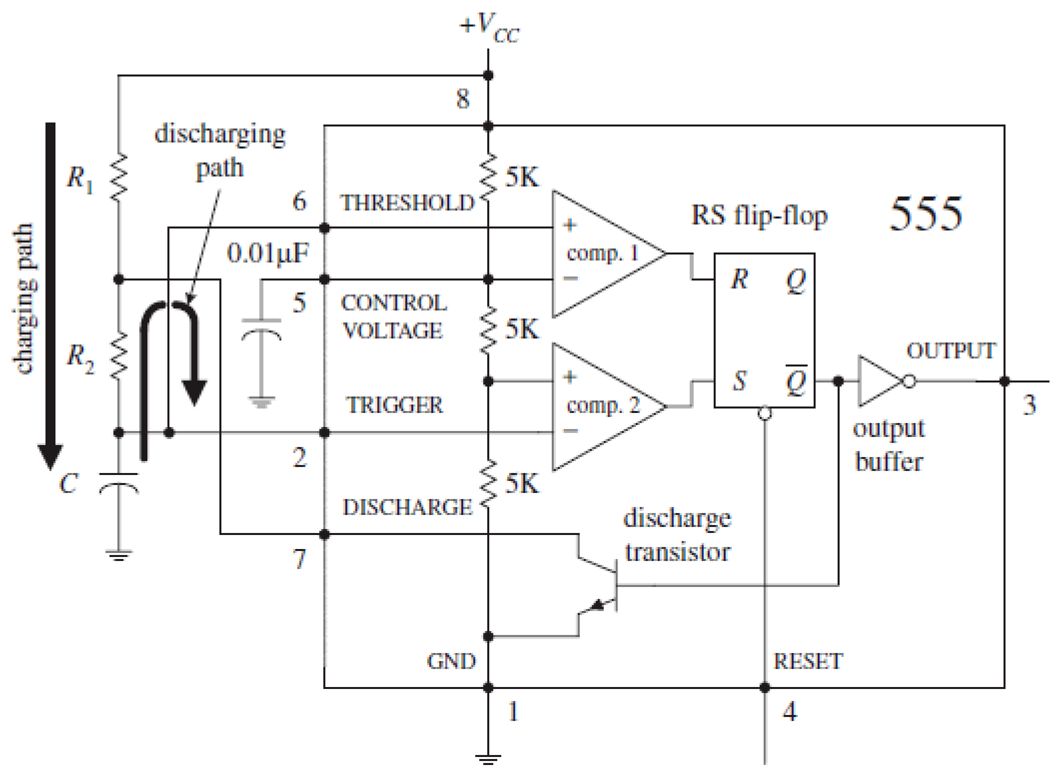


Figure 10.6.

The NE555 Timer: Astable Mode

The 555 timer gets its name from these 3 5kΩ resistors:

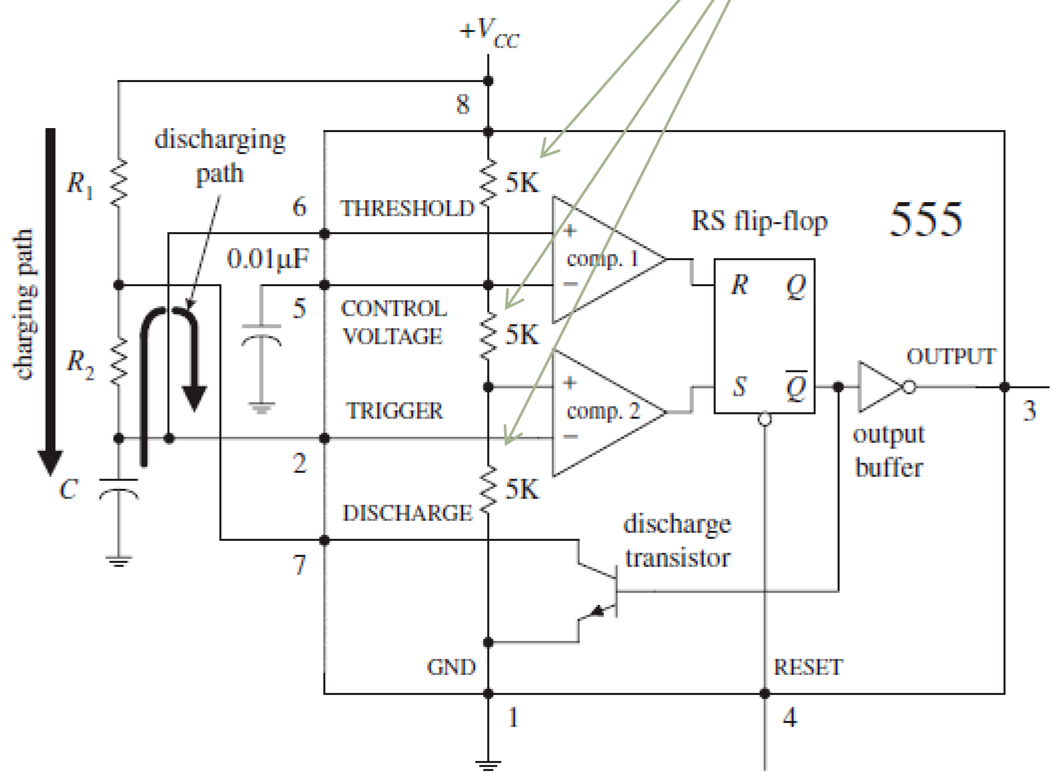


Figure 10.6.

These resistors act as a three step Voltage divider between the Supply voltage (Vcc) and the ground reference voltage

The NE555 Timer: Astable Mode

The 555 timer gets its name from these 3 5kΩ resistors:

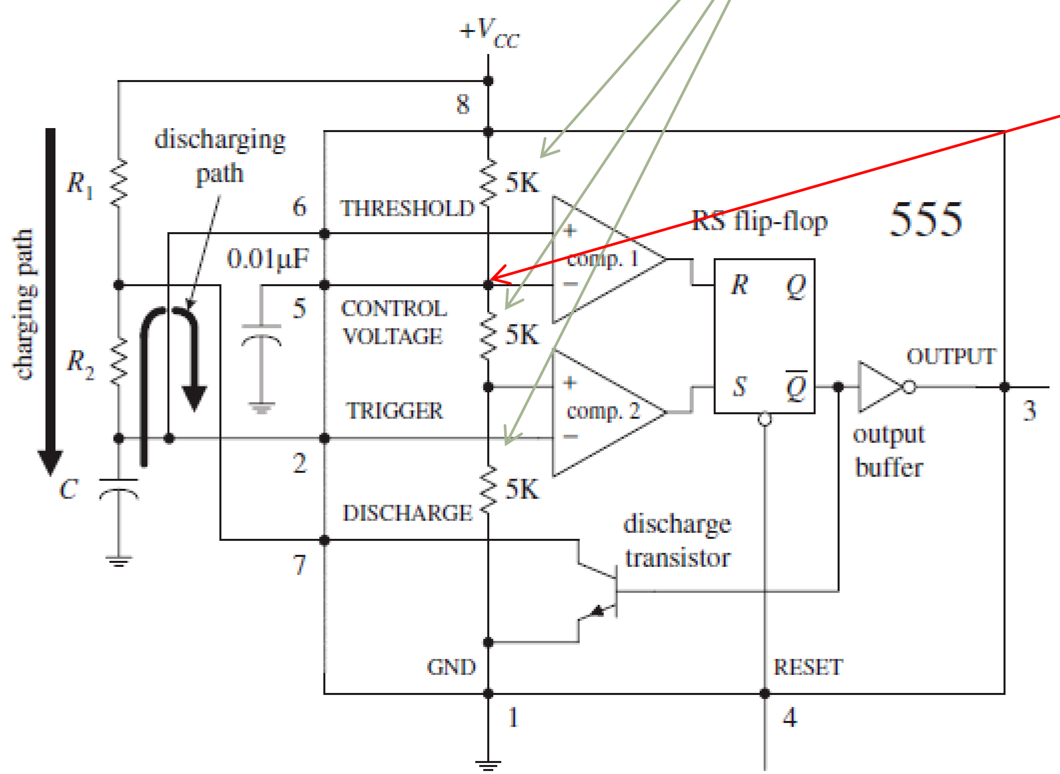


Figure 10.6.

These resistors ensure that the Voltage at The –ve Terminal of comparator 1 is 0.67 of Vcc

The NE555 Timer: Astable Mode

The 555 timer gets its name from these 3 5kΩ resistors:

And that the Voltage at The +ve Terminal of comparator 2 is 0.33 of Vcc

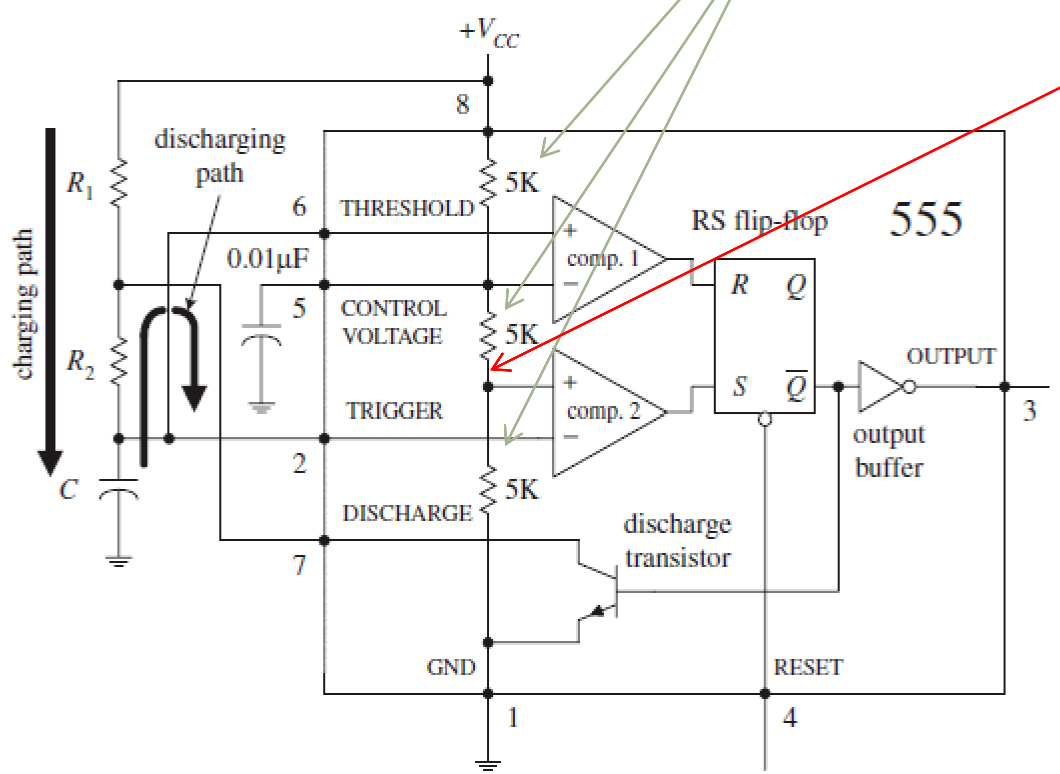


Figure 10.6.

The NE555 Timer: Astable Mode

The two comparators output either a high or low voltage based on the analog voltages being compared at their inputs

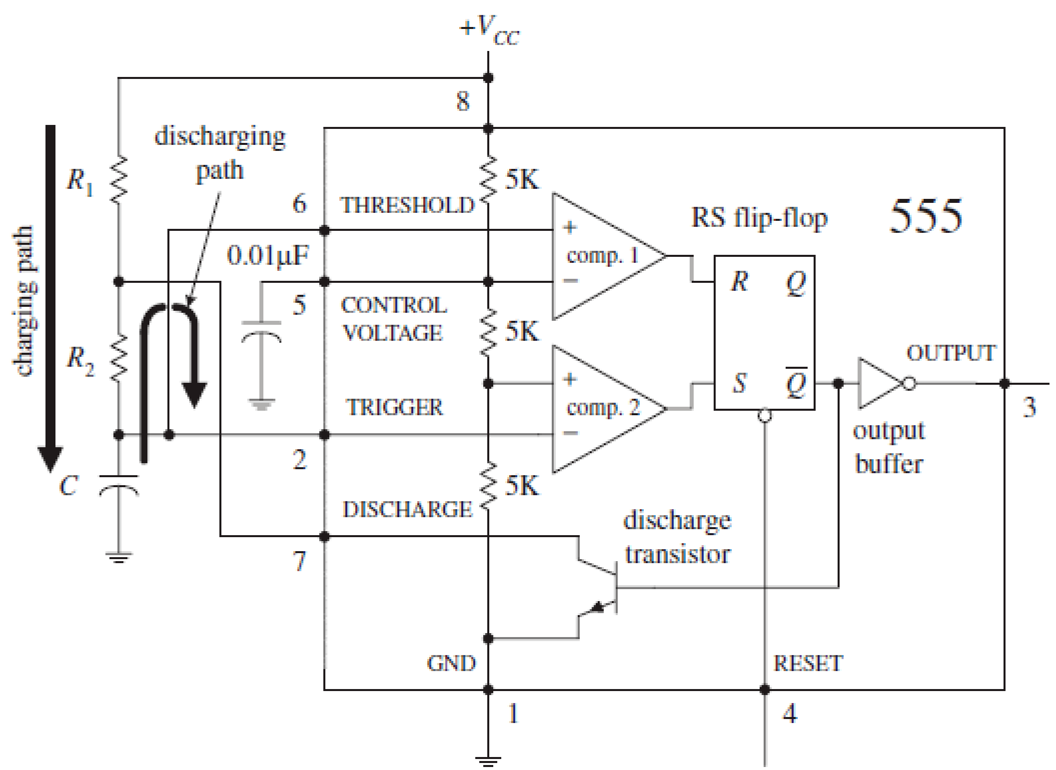


Figure 10.6.

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The NE555 Timer: Astable Mode

If one of the comparator's positive inputs is more positive than its negative input, its output logic level goes high

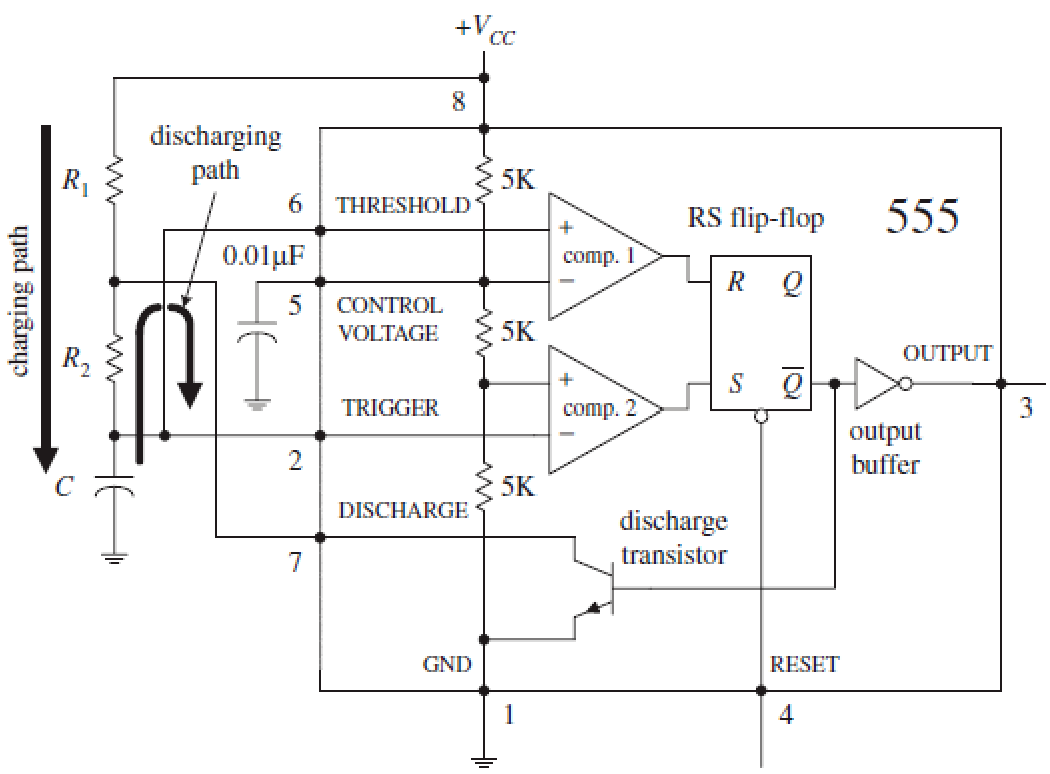

Figure 10.6.

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The NE555 Timer: Astable Mode

if the positive input voltage is less than the negative input voltage, the output logic level goes low

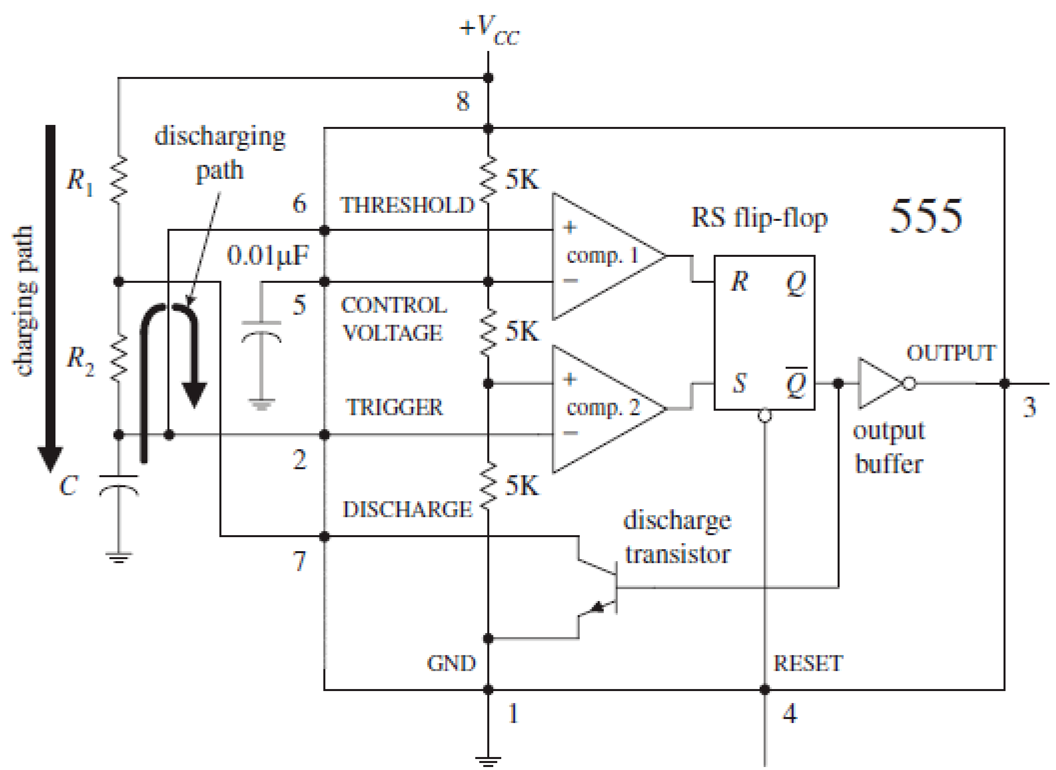

Figure 10.6.

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The NE555 Timer: Astable Mode

The outputs of the comparators are sent to the inputs of an *SR* (set/reset) flip-flop.

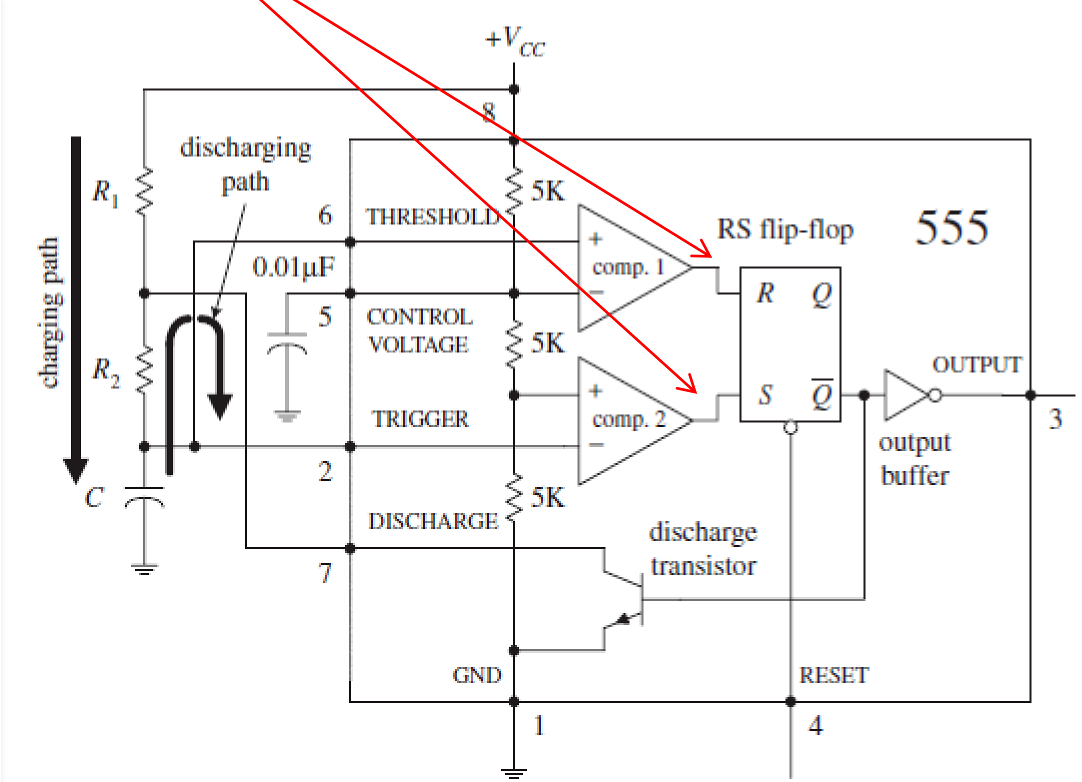

Figure 10.6.

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The NE555 Timer: Astable Mode

The flip-flop looks at the *R* and *S* inputs and produces either a high or a low based on the voltage states at the inputs

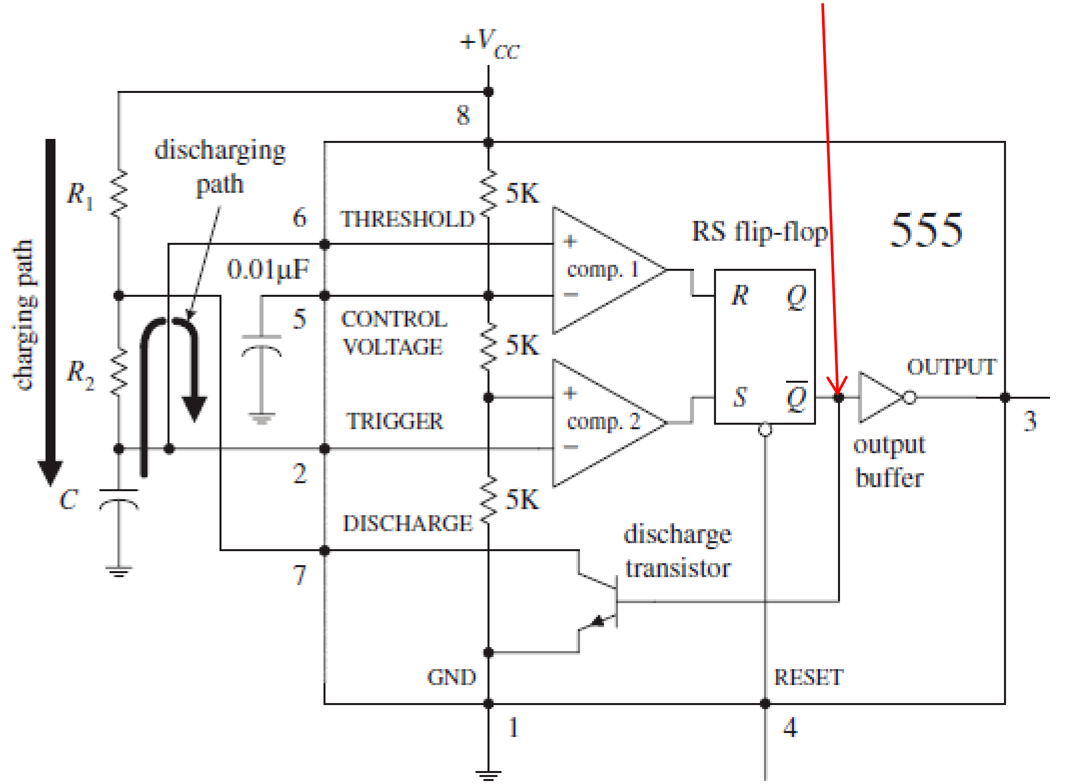

Figure 10.6.

The NE555 Timer: Astable Mode

Looking at Pin 1, this is the ground or reference pin and should be connected to the ground of the circuit (usually 0 Volts)

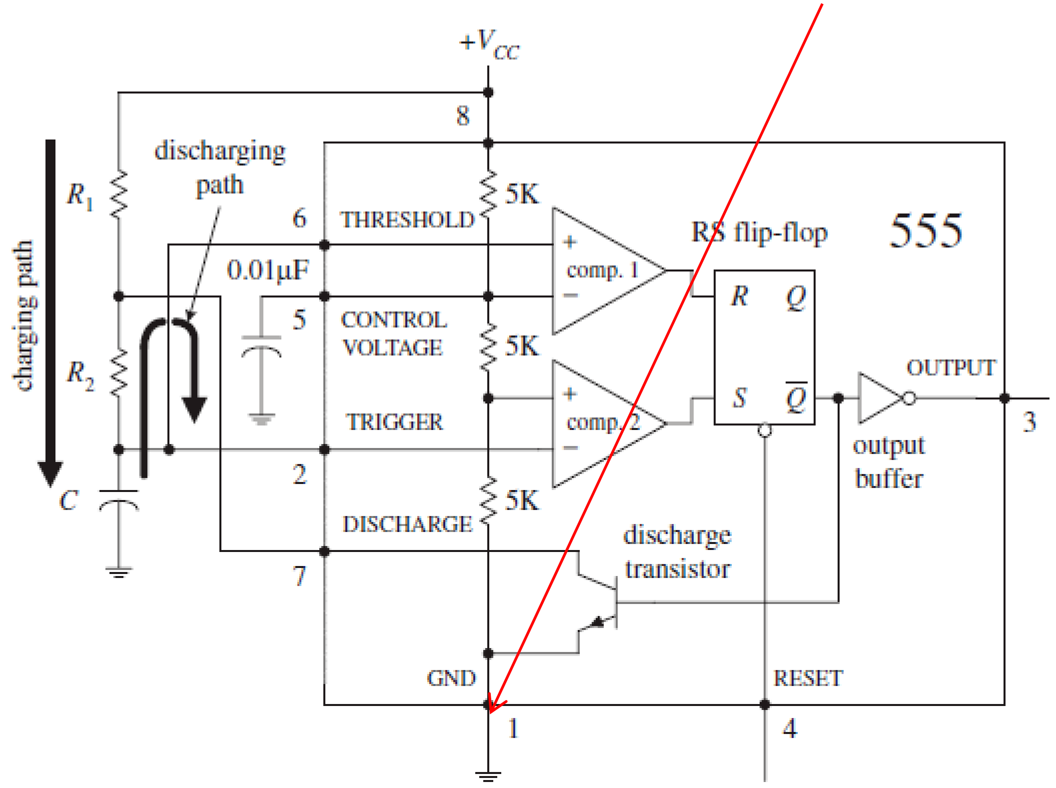

Figure 10.6.

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The NE555 Timer: Astable Mode

<u>Looking at Pin 2</u>, this is **<u>trigger</u>** input and is connected to comparator 2, which is used to set the flip-flop, When the voltage at pin 2 crosses from above to below $^{1}/_{3}V_{CC}$, the comparator switches to high, setting the flip-flop.

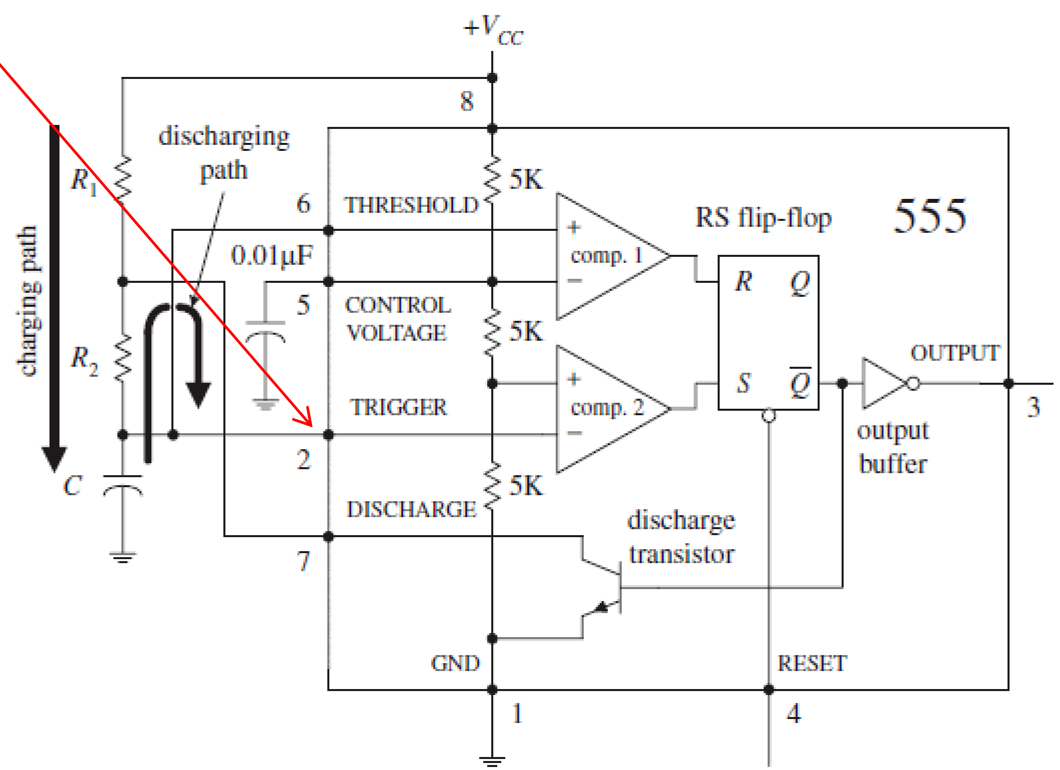

Figure 10.6.

The NE555 Timer: Astable Mode

Looking at Pin 3 (output), The output of the 555 is driven by an inverting buffer capable of sinking or sourcing around 200 mA. The output voltage levels depend on the output current but are approximately $V_{out(high)} = V_{CC}$ - 1.5 V and $V_{out(low)}$ = 0.1 V.

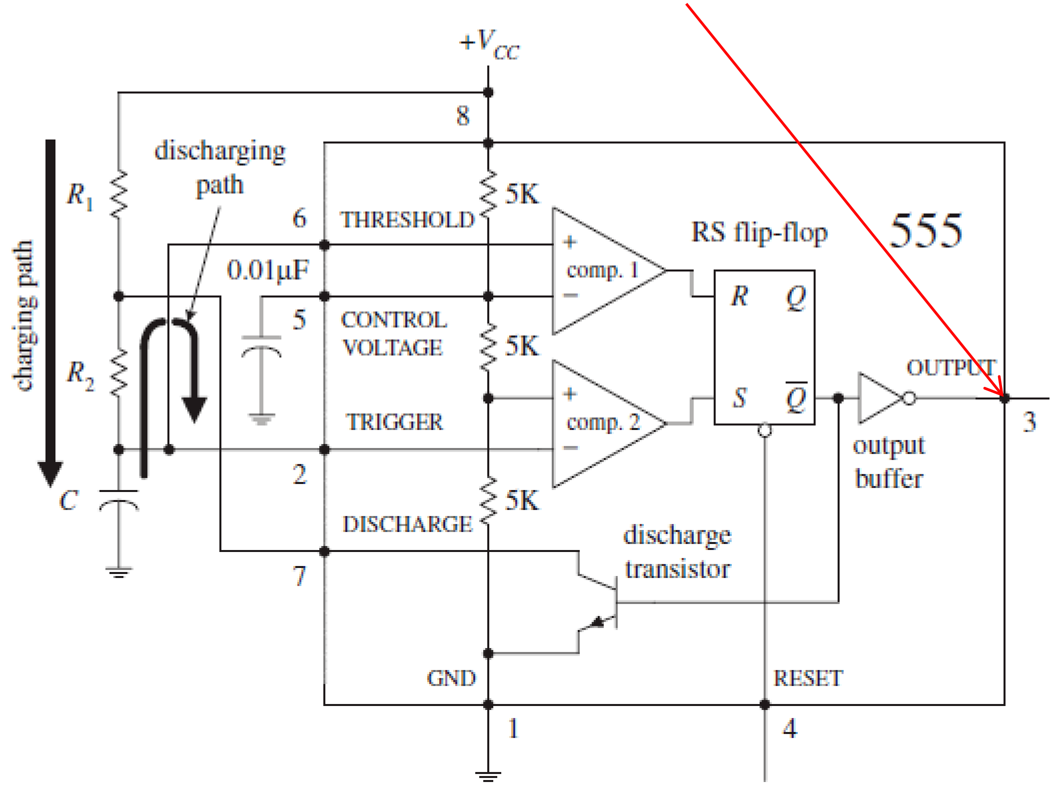

Figure 10.6.

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The NE555 Timer: Astable Mode

Looking at Pin 4, Active-low **reset**, which forces $\bar{Q}$ high and pin 3 (output) low.

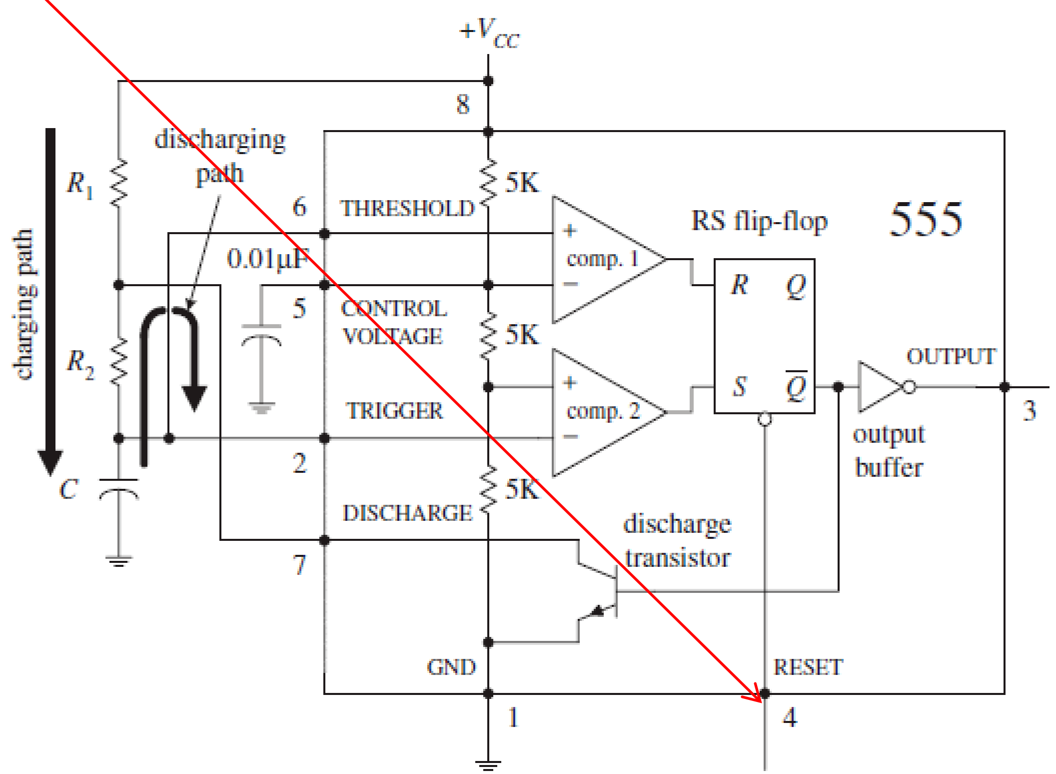

Figure 10.6.

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The NE555 Timer: Astable Mode

<u>Looking at Pin 5 (control)</u>, Used to override the $^{2}/_{3}V_{CC}$ level, if needed, but is usually grounded via a 0.01-µF bypass capacitor (the capacitor helps eliminate V_{CC} supply noise). An external voltage applied here will set a new trigger voltage level.

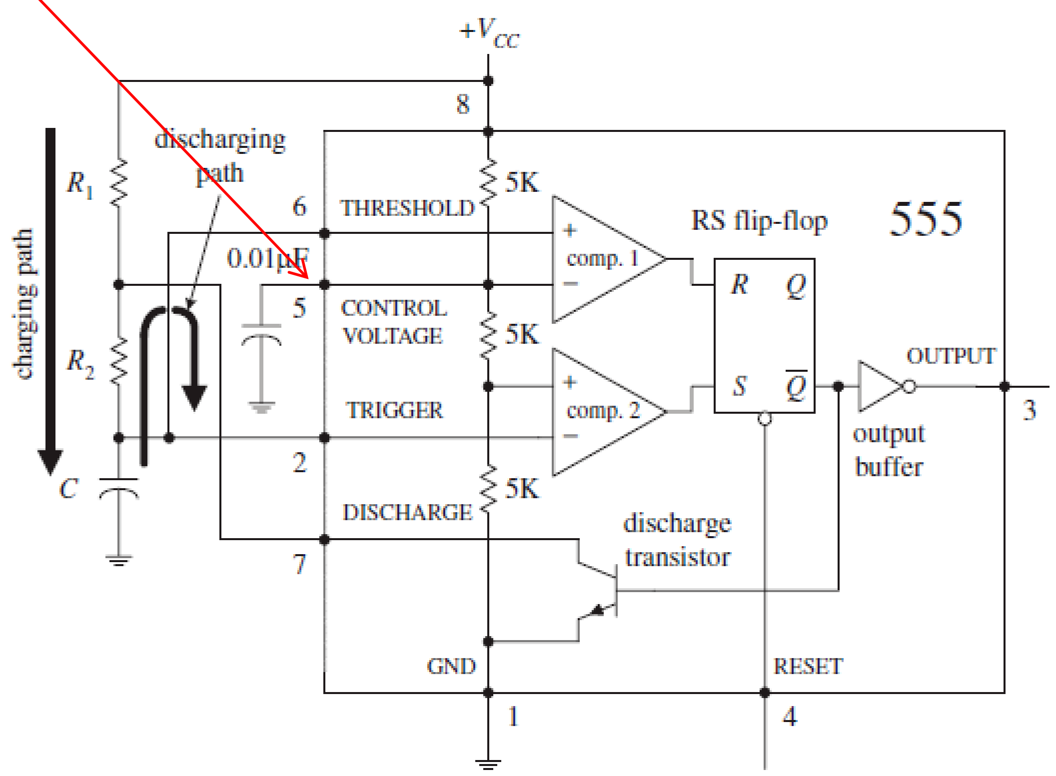

Figure 10.6.

The NE555 Timer: Astable Mode

Looking at Pin 6 (threshold), Input to the upper comparator, which is used to reset the flip-flop. When the voltage at pin 6 crosses from below to above $^2/_3V_{CC}$, the comparator switches to a high, resetting the flip-flop.

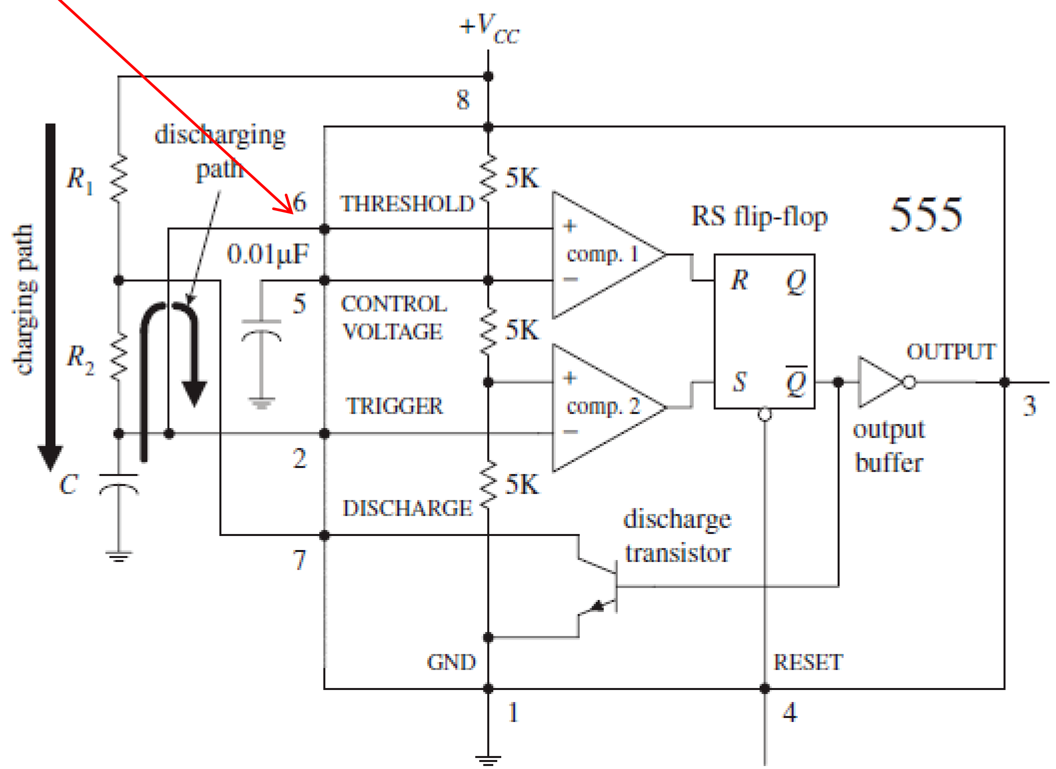

Figure 10.6.

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The NE555 Timer: Astable Mode

<u>Looking at Pin 7 (discharge)</u>, Connected to the open collector of the *npn* transistor. It is used to short pin 7 to ground when $\bar{Q}$ is high (pin 3 low). This causes the capacitor to discharge.

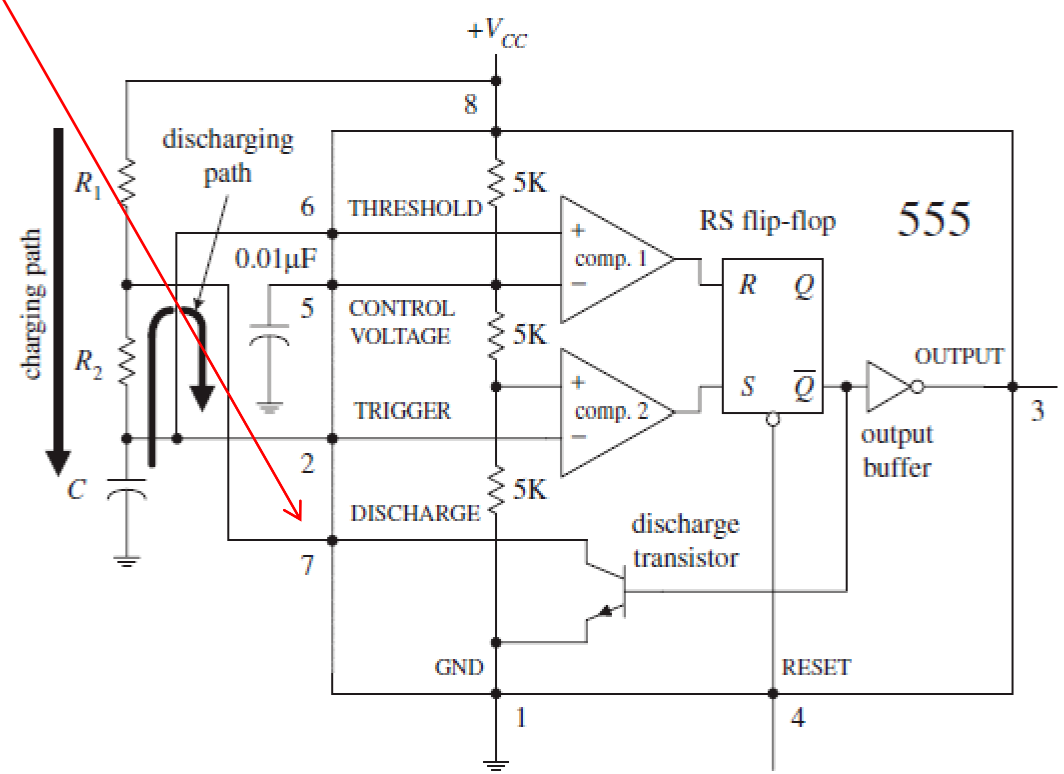

Figure 10.6.

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The NE555 Timer: Astable Mode

Looking at Pin 8 (supply voltage), Typically between 4.5 and 16 V for general-purpose TTL 555 timers. (For CMOS versions, the supply voltage may be as low as 1 V.)

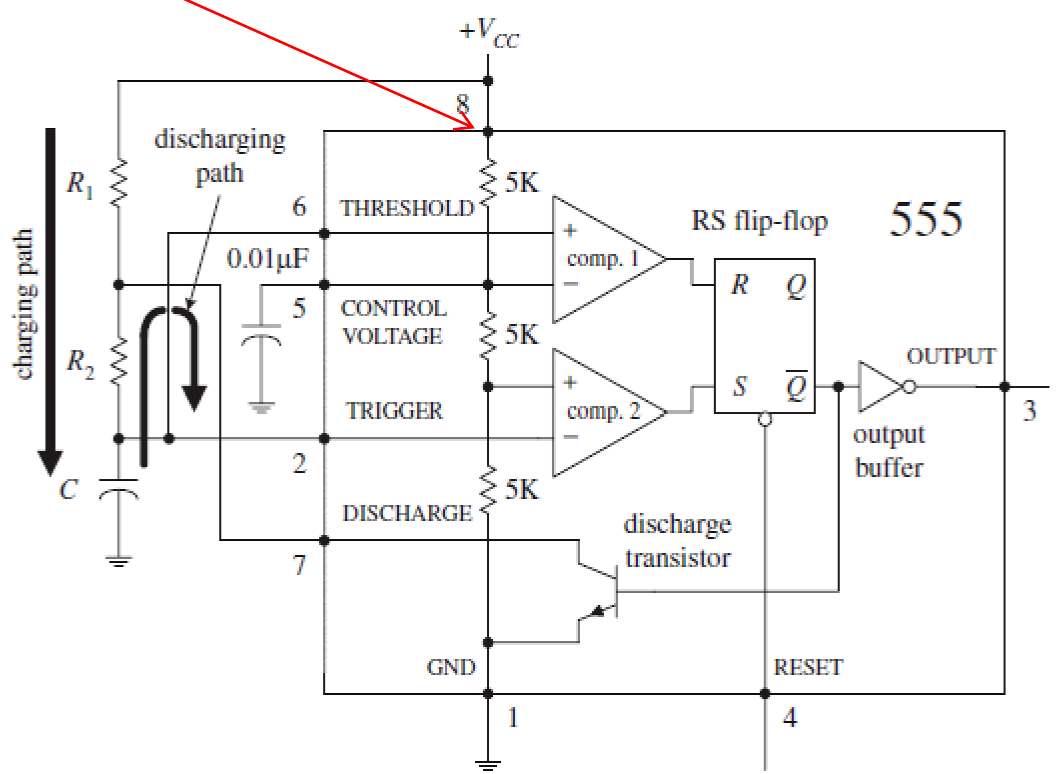

Figure 10.6.

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The NE555 Timer: Astable Mode

In the astable configuration, when power is first applied to the system, the capacitor is uncharged. This means that 0 V is placed on pin 2, forcing comparator 2 high.

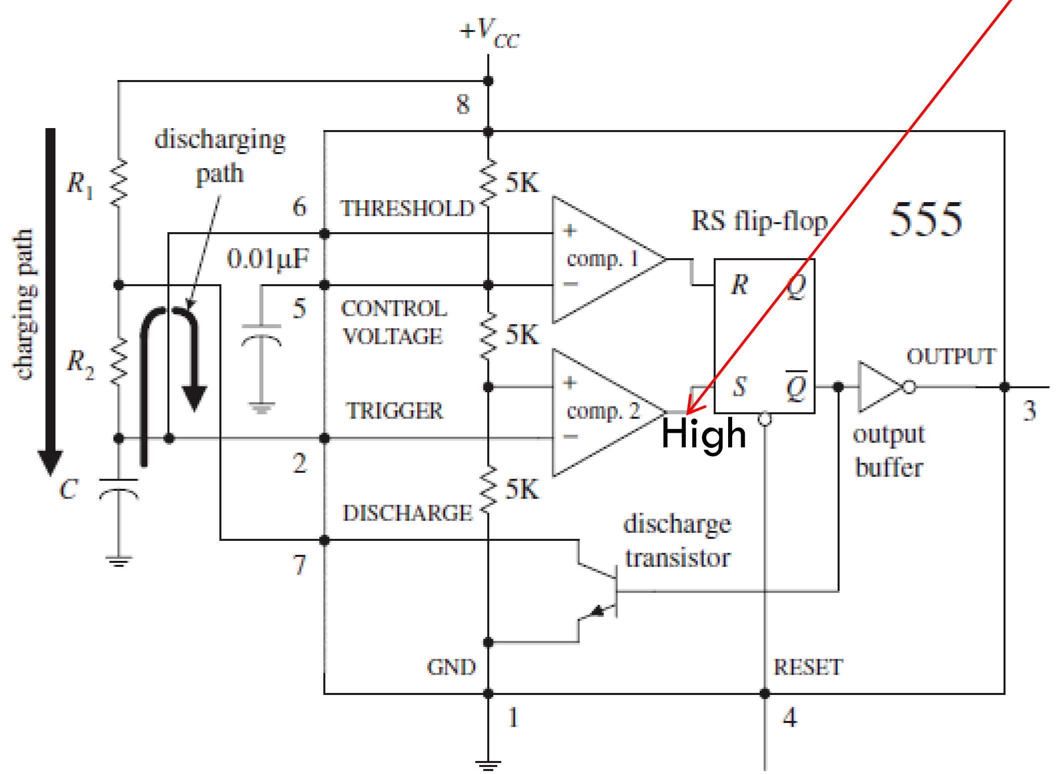

Figure 10.6.

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The NE555 Timer: Astable Mode

This in turn sets the flip-flop so that $\bar{Q}$ is Low and the 555's output is High (a result of the inverting buffer).

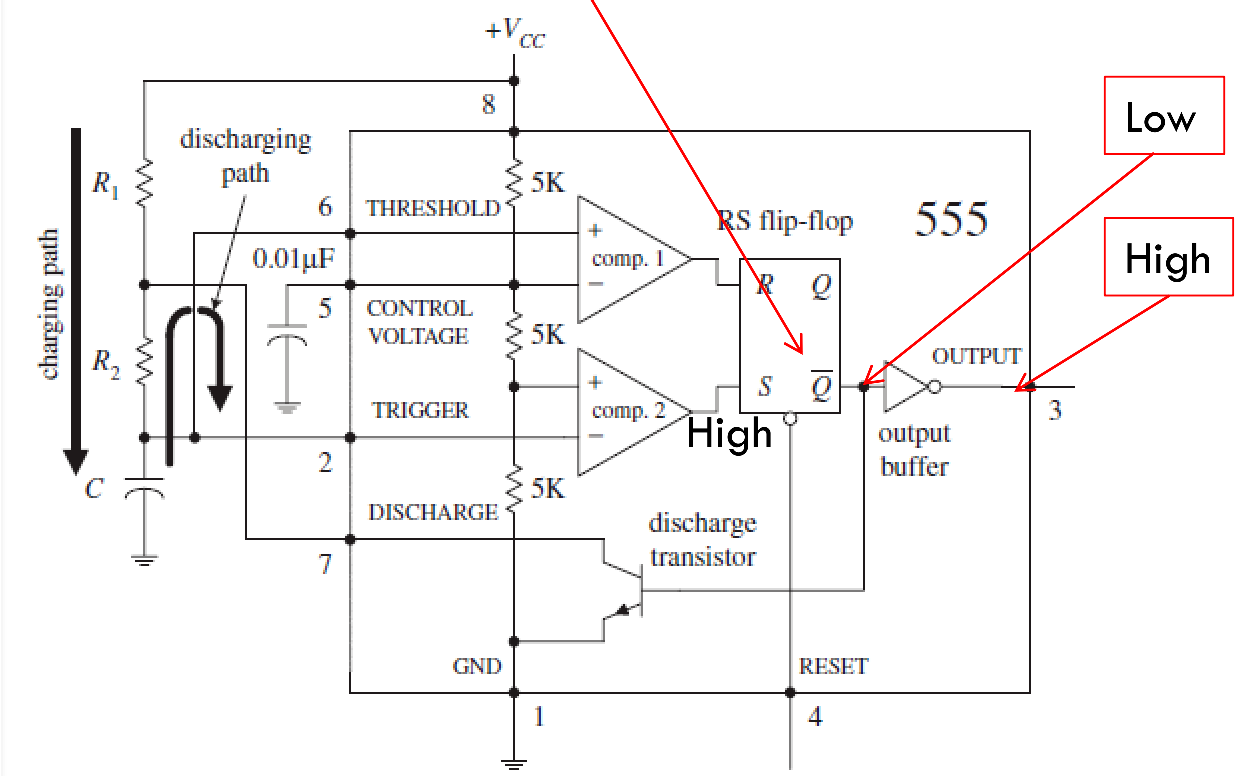

Figure 10.6.

The NE555 Timer: Astable Mode

With the output $\bar{Q}$ low, the discharge transistor is turned OFF . So the capacitor will start to charge through V_{CC} R_1 and R_2 charging path

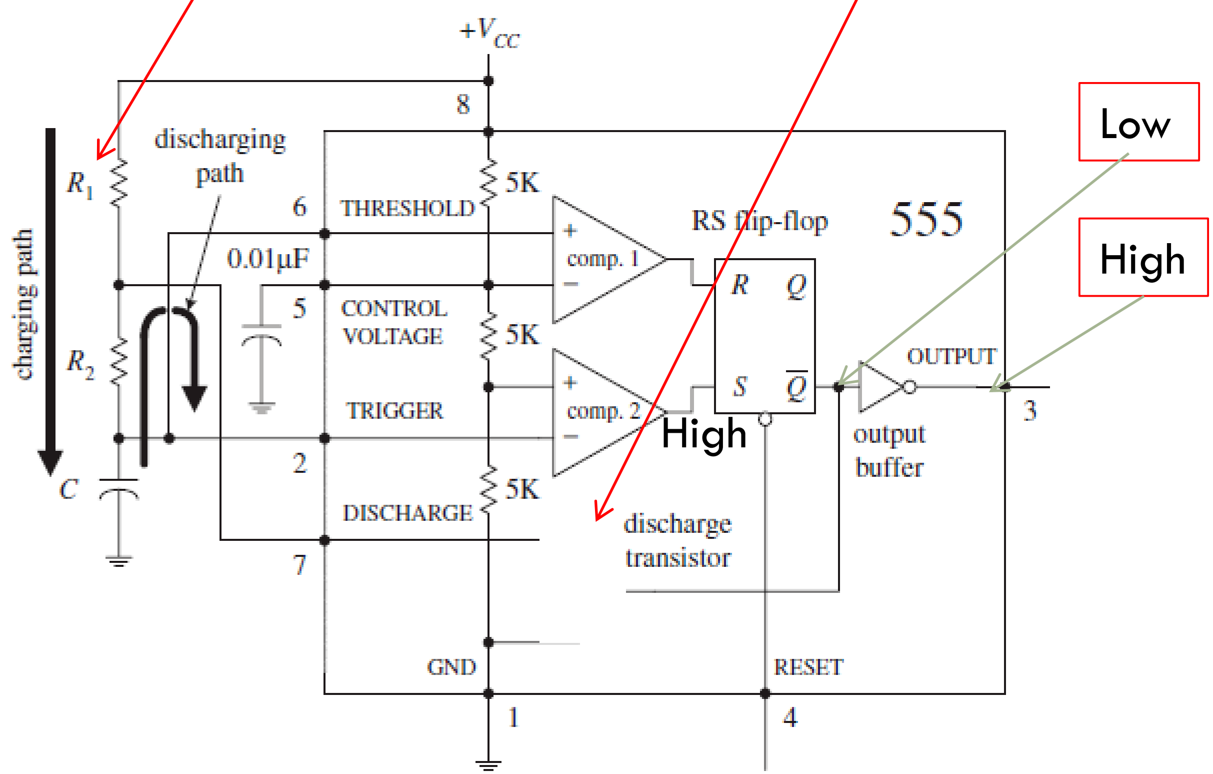

Figure 10.6.

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The NE555 Timer: Astable Mode

When this voltage exceeds $^{1}/_{3}V_{CC}$, comparator 2 goes low, which has no effect on the *SR* flip-flop.

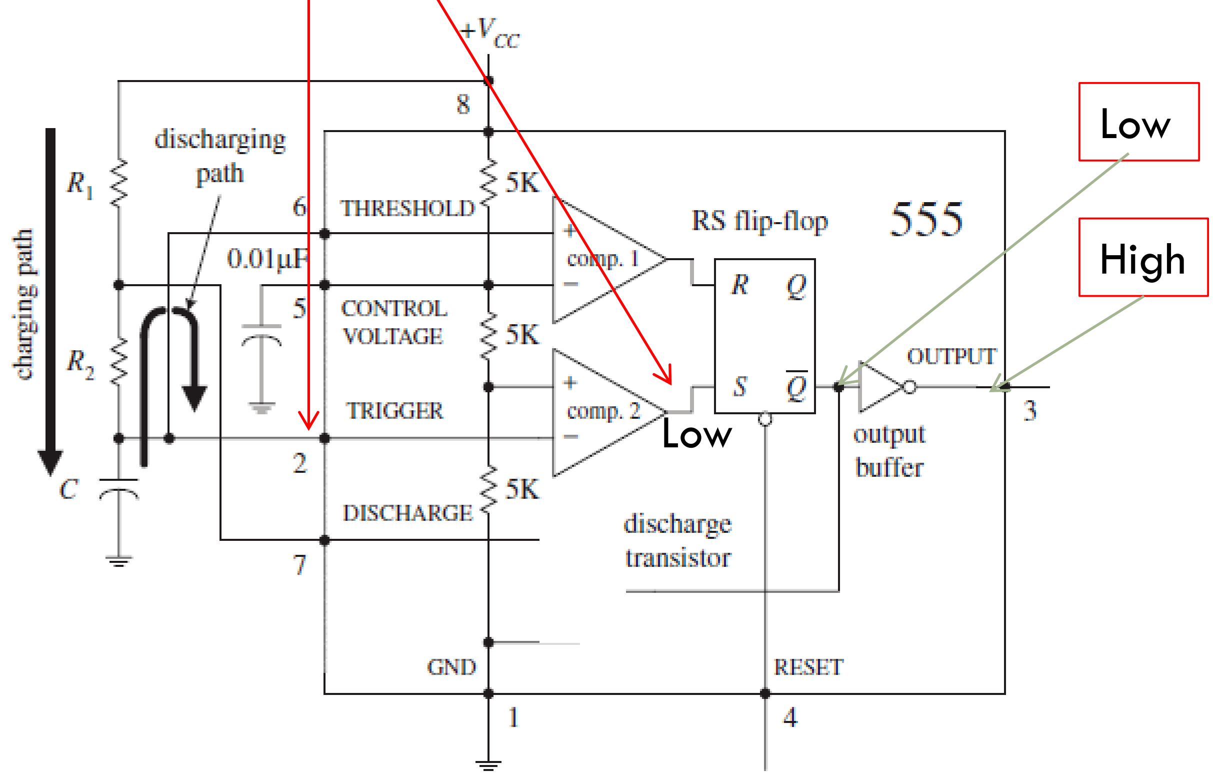

Figure 10.6.

The NE555 Timer: Astable Mode

When this voltage exceeds $^2/_3 V_{CC}$, comparator 1 goes high, resetting the flip-flop and forcing $\bar{Q}$ High and the output now goes Low

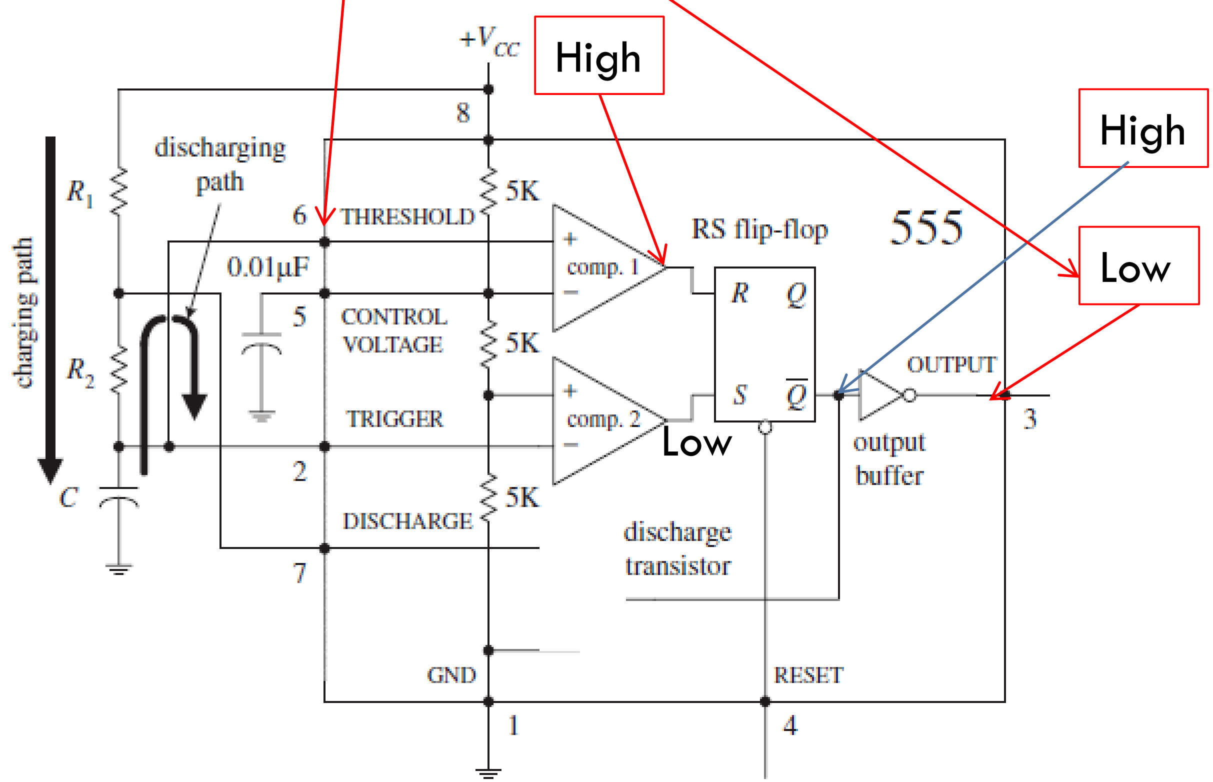

Figure 10.6.

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The NE555 Timer: Astable Mode

At this same instant the discharge transistor is turned ON, shorting pin 7 to ground and the capacitor starts discharging through R_2

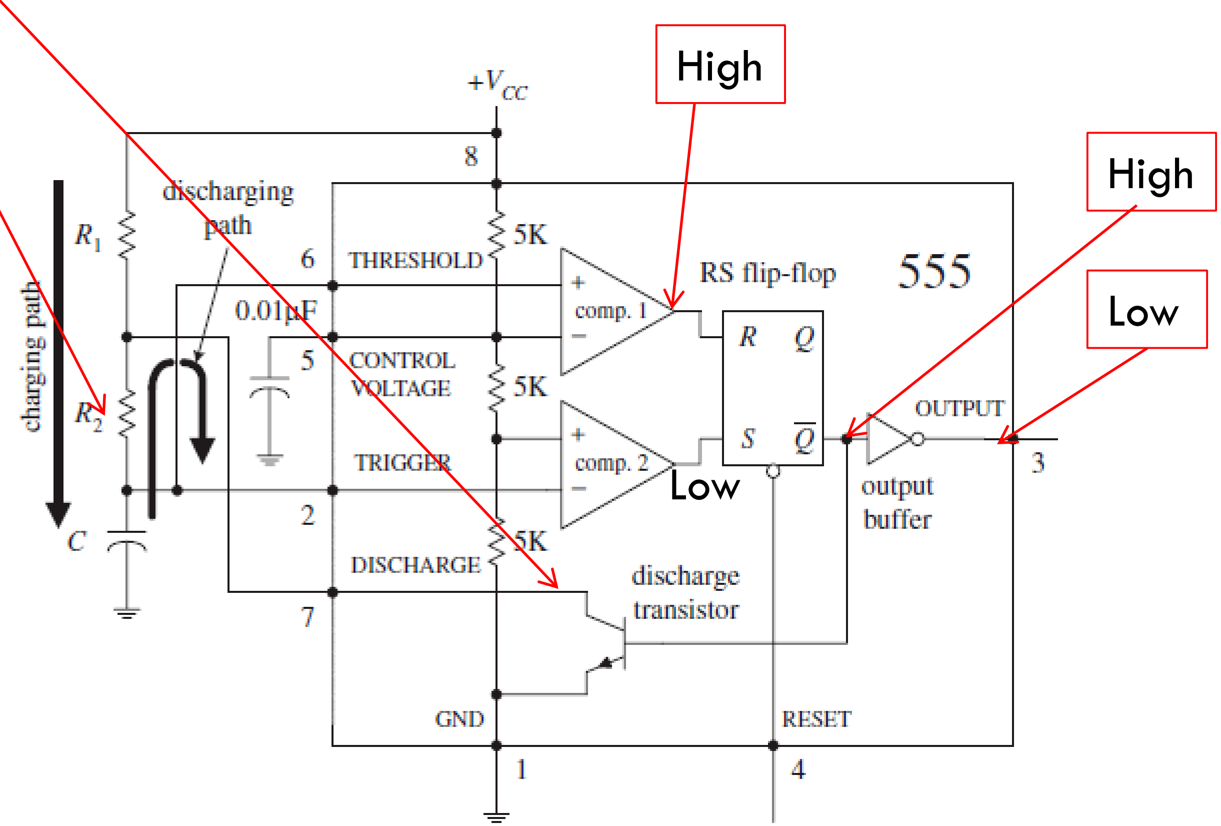

Figure 10.6.

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The NE555 Timer: Astable Mode

This discharge will next drop the voltage below $^2/_3 V_{CC}$ which will set the output of comparator 1 Low again, but will not change the state of the RS flip flop

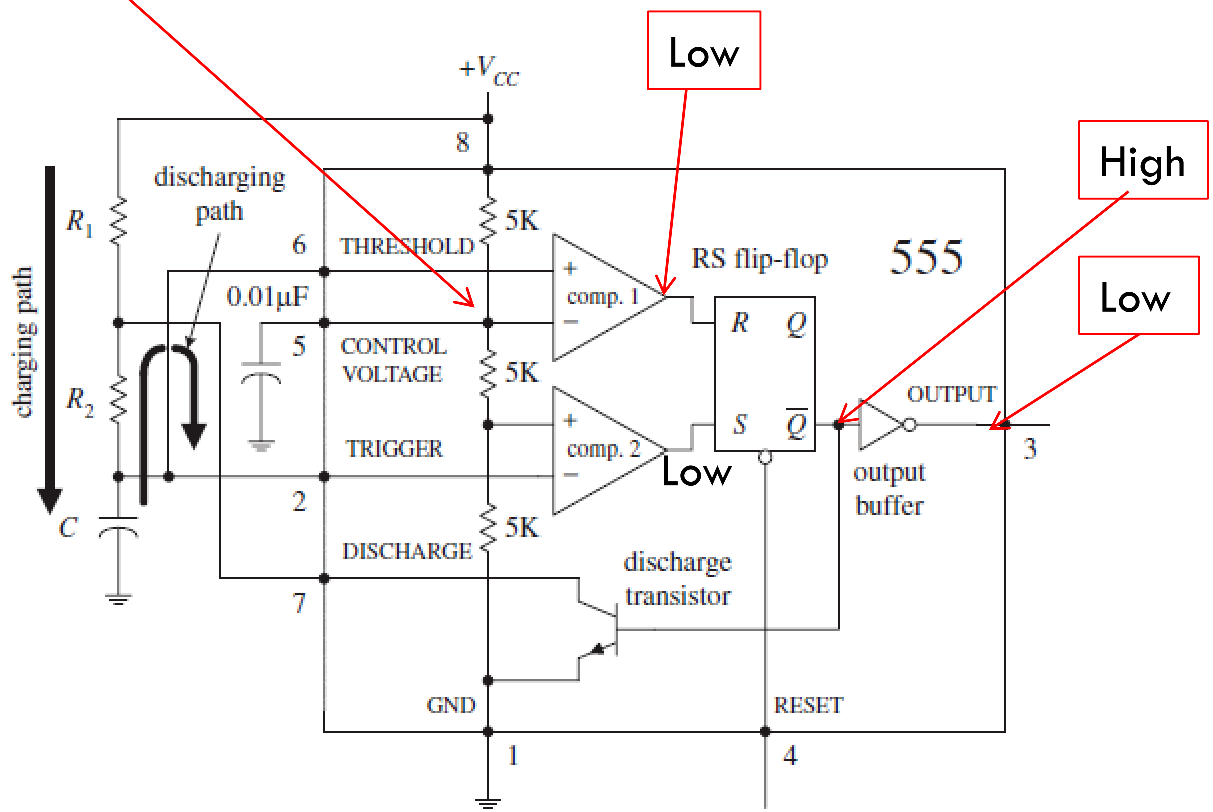

Figure 10.6.

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The NE555 Timer: Astable Mode

When the capacitor's voltage drops below $^1/_3V_{CC}$, comparator 2's output jumps back to a high level, setting the RS flip-flop, turning off the discharge transistor, placing the output high and the capacitor starts to charge again and the cycle starts again…..

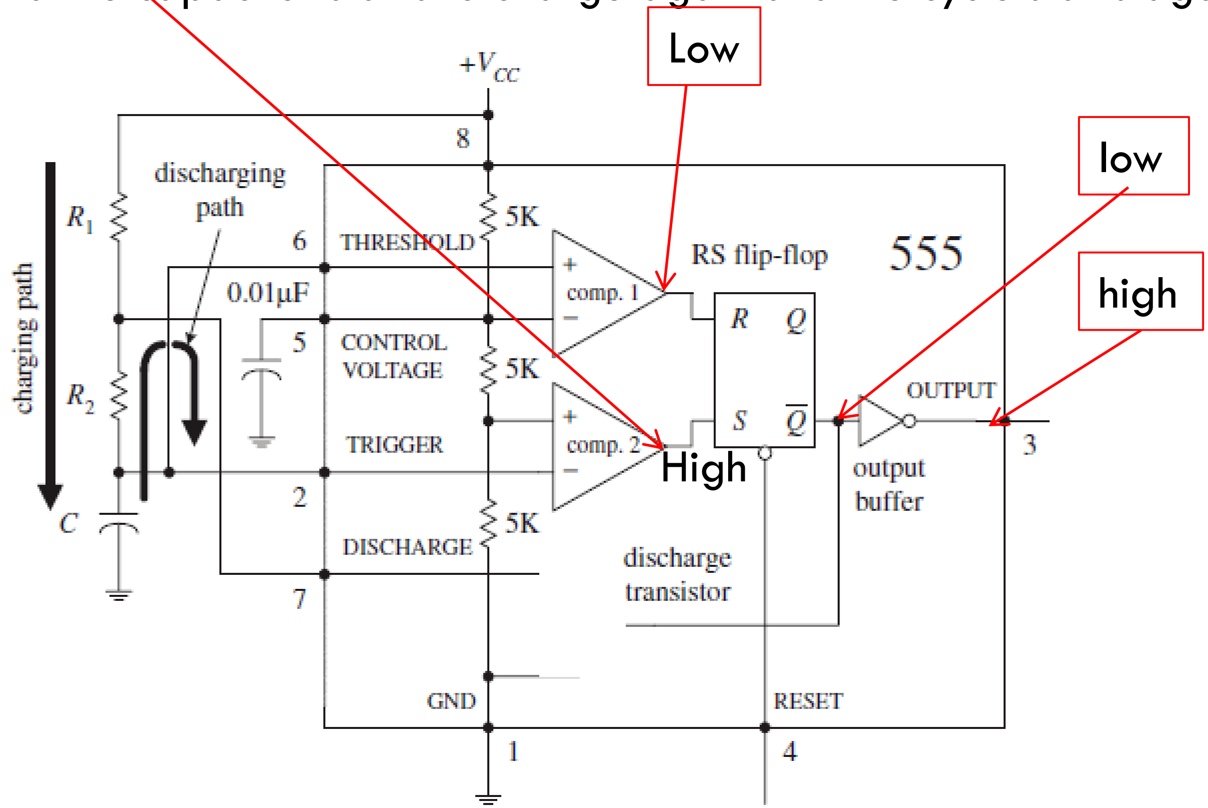

Figure 10.6.

The NE555 Timer: Astable Mode

- So in astable mode we end up with a rectangular output at pin 3 (the output)
- Its voltage level is approximately V_{CC} - 1.5 V
- Its on/off periods are determined by the values of C, R_1 and R_2

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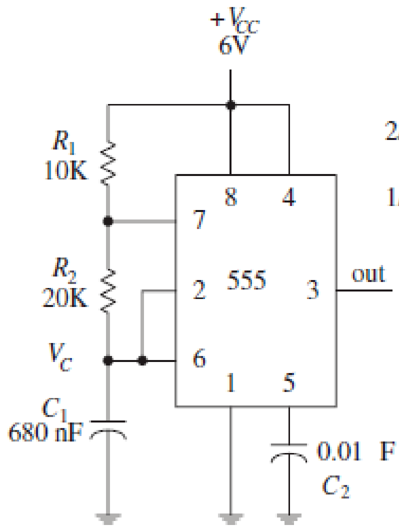
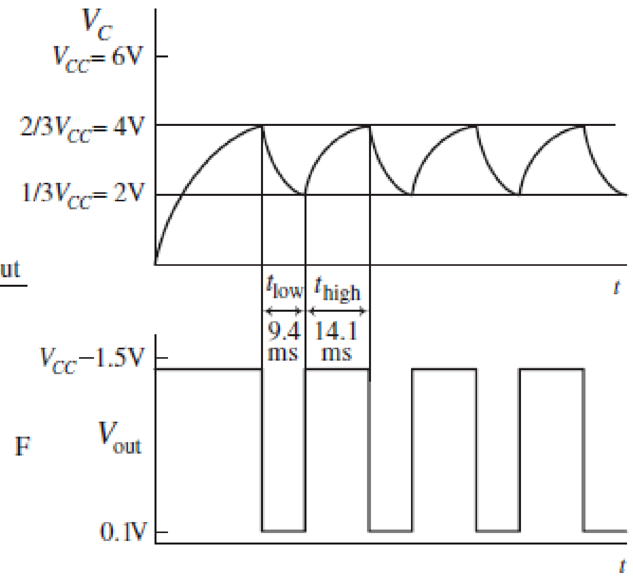
The NE555 Timer: Astable Mode





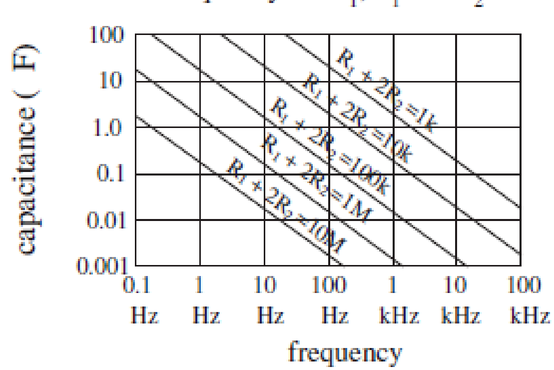
$t_{low} = 0.693(20K)(680nF) = 9.6ms$

$t_{high} = 0.693(10K + 20K)(680nF) = 14.1ms$

$$f = \frac{1}{9.4ms + 14.1ms} = 42Hz$$

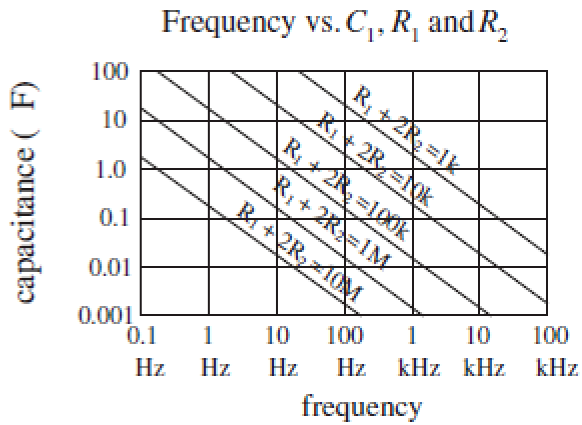
$$\text{duty cycle} = \frac{14.1ms}{14.1ms + 9.4ms} = 0.6$$

Frequency vs. C_1, R_1 and R_2



The NE555 Timer: Astable Mode

- When a 555 is set up in astable mode, it has no stable states; the output jumps back and forth
- The time duration V_{out} remains low (around 0.1 V) is set by the R_2C_1 time constant and the $1/3V_{CC}$ and $2/3V_{CC}$ levels;
- the time duration V_{out} stays high (around V_{CC} - 1.5 V) is determined by the $(R_1 + R_2)C_1$ time constant and the two voltage levels;



- It can be shown that these relationships are useful:

$$t_{low} = 0.693R_2C_1$$

$$t_{high} = 0.693(R_1 + R_2)C_1$$

UNIVERSITY OF WOLLONGONG IN DUBAI

The NE555 Timer: Astable Mode

The duty cycle (the fraction of the time the output is high) is given by:

$$\text{Duty Cycle} = \frac{t_{high}}{t_{low} + t_{high}}$$

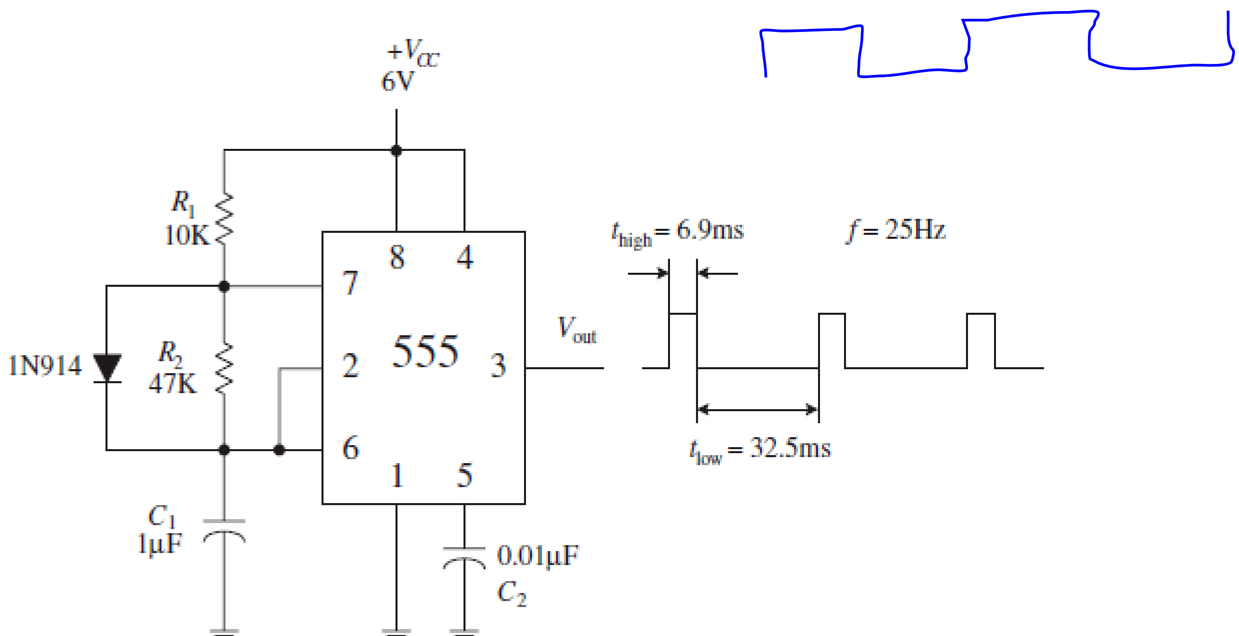
The frequency of the output waveform is:

$$f = \frac{1}{t_{low} + t_{high}} = \frac{1.44}{(R_1 + 2R_2)C_1}$$

For reliable operation, the resistors should be between approximately 10 kΩ and 14 MΩ, and the timing capacitor should be from around 100 pF to 1000 µF.

Low-Duty-Cycle Operation

- Now there is a slight problem with the last circuit—you cannot get a duty cycle that is below 0.5 (or 50 percent)
- If you need this use this modification (add diode across R_2)

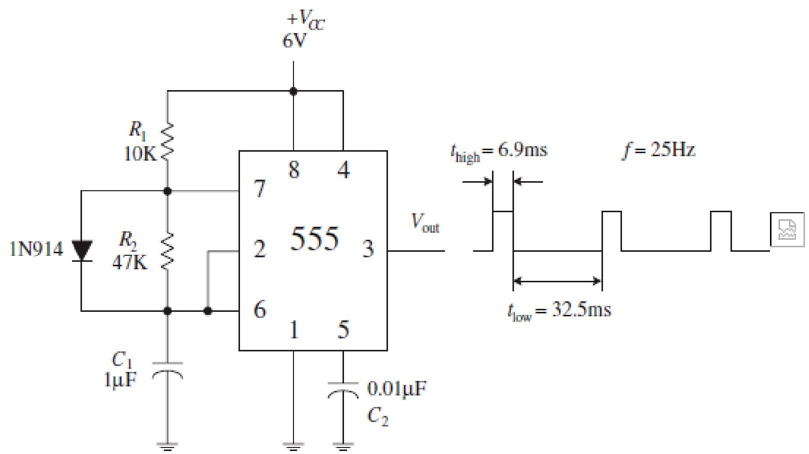


Low-Duty-Cycle Operation

With the diode in place, as the capacitor is charging (generating t_{high}), the preceding time constant $(R_1 + R_2)C_1$ is reduced to R_1C_1 because the charging current is diverted around R_2 through the diode. With the diode in place, the high and low times become:

$$t_{high} = 0.693R_1C_1$$

$$t_{low} = 0.693R_2C_1$$



With the diode in place to generate a duty cycle of less than 0.5, or 50 percent, simply make R_1 less than R_2.

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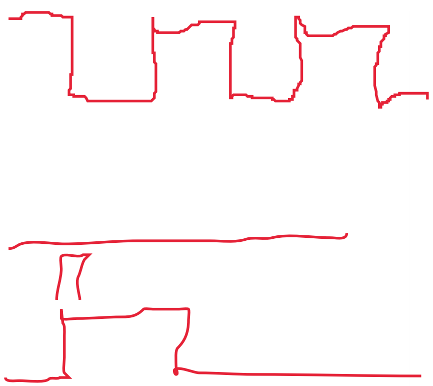
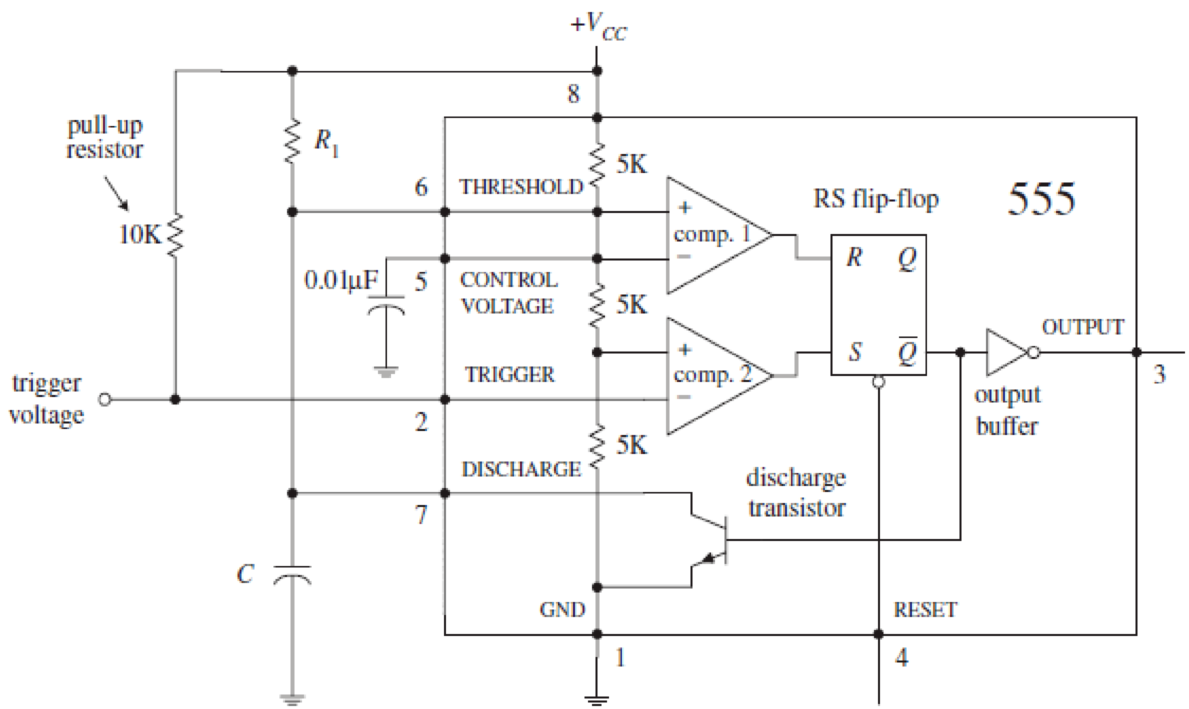
The NE555 Timer: Monostable Mode

- Monostable mode, also called Timer Mode (typical configuration below)
- Main difference is it **requires an external trigger** which is held high via a pull-up resistor and the trigger will put it low starting a new cycle time (but a one-off timer, needing another trigger event to start again).



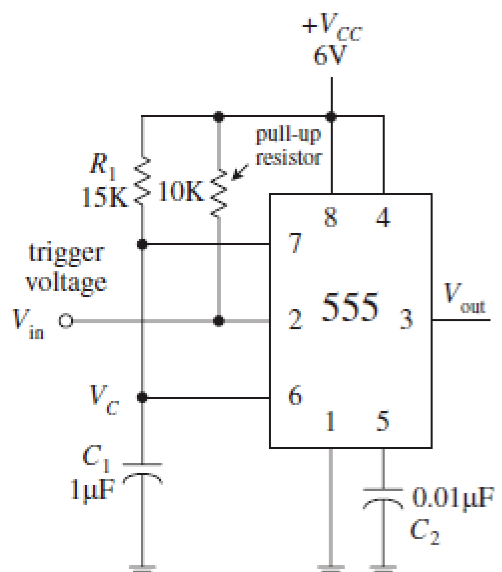


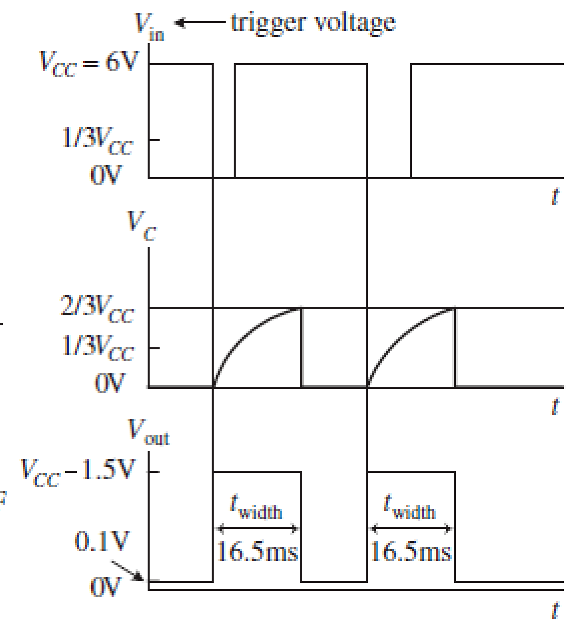
The NE555 Timer: Monostable Mode

- The monostable circuit only has one stable state. That is, the output rests at 0 V (in reality, more like 0.1 V) until a negative-going trigger pulse is applied to the trigger lead—pin 2
  - The negative-going pulse can be implemented by momentarily grounding pin 2, say, by using a pushbutton switch attached from pin 2 to ground
- After the trigger pulse is applied, the output will go high (around V_{CC} - 1.5 V) for the duration set by the R_1C_1 network.
- the width of the high output pulse is

$$t_{width} = 1.1R_1C_1$$

- For reliable operation, the timing resistor R_1 should be between around 10 kΩ and 14 MΩ, and the timing capacitor should be from around 100 pF to 1000 µF





$t_{width} = 1.10\ R_1C_1$

$t_{width} = 1.10\ (15\text{K})(1\mu\text{F}) = 16.5\text{ms}$

555 Practical Tips

- To avoid problems associated with false triggering, connect the 555's pin 5 to ground through a 0.01-μF capacitor

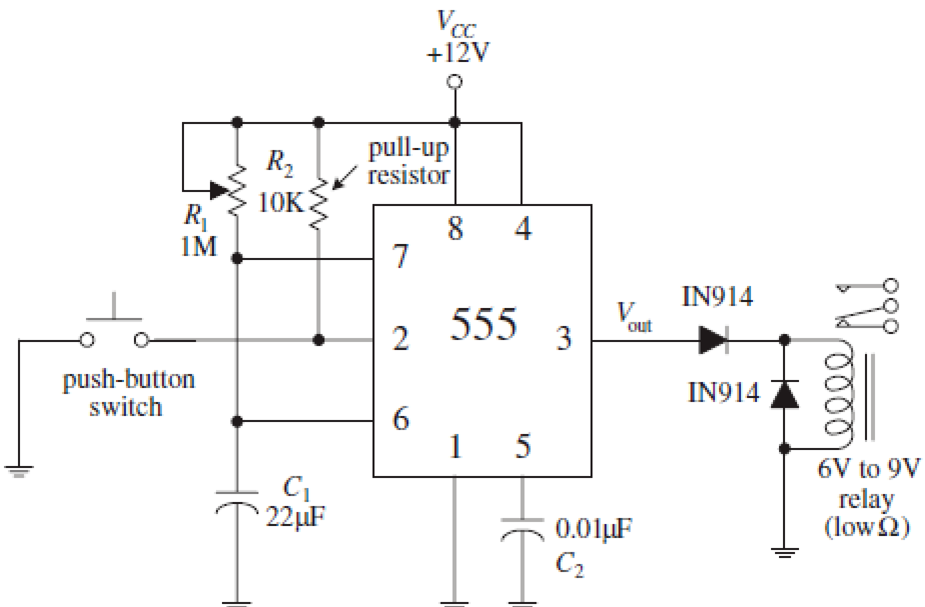
- if the power supply lead becomes long or the timer does not seem to function for some unknown reason, try attaching a 0.1-μF or larger capacitor between pins 8 and 1.

555 Applications: Relay Driver (Delay Timer)

- The **monostable** circuit shown above acts as a delay timer that is used to actuate a relay for a given duration.
- With the pushbutton switch open, the output is low (around 0.1 V), and the relay is at rest.
- However, when the switch is momentarily closed, the 555 begins its timing cycle; the output goes high (in this case ~10.5 V) for a duration equal to

$$t_{delay} = 1.1R_1C_1$$

www.youtube.com/watch?app=desktop&v=eY1E0XE4olQ
www.youtube.com/watch?v=37sYoHkbGQs
www.youtube.com/watch?app=desktop&v=qYSmdWRsRrM
www.youtube.com/watch?app=desktop&v=3XeQVFOlc_g



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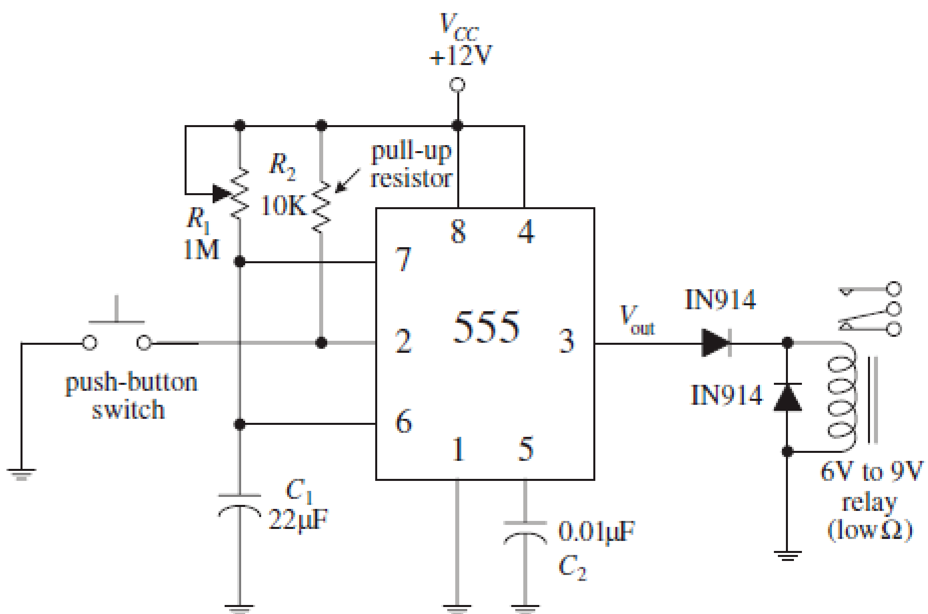
555 Applications: Relay Driver (Delay Timer)

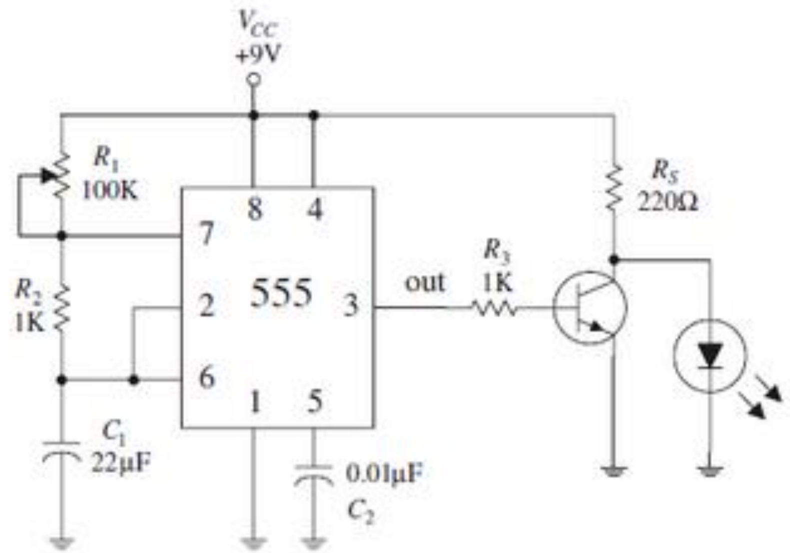
- The relay will be actuated for the same time delay
- The two diodes in the circuit near the relay and across the relay help prevent damaging surge currents generated when the relay switches states to prevent damage to the 555 IC as well as the relays switch contacts

$$t_{delay} = 1.1R_1C_1$$



555 Applications: LED Flasher

- Circuit is an oscillator circuit (astable multivibrators)



- a transistor is used to amplify the *555*'s output in order to provide sufficient current to drive the LED, while R_S is used to prevent excessive current from damaging the LED.

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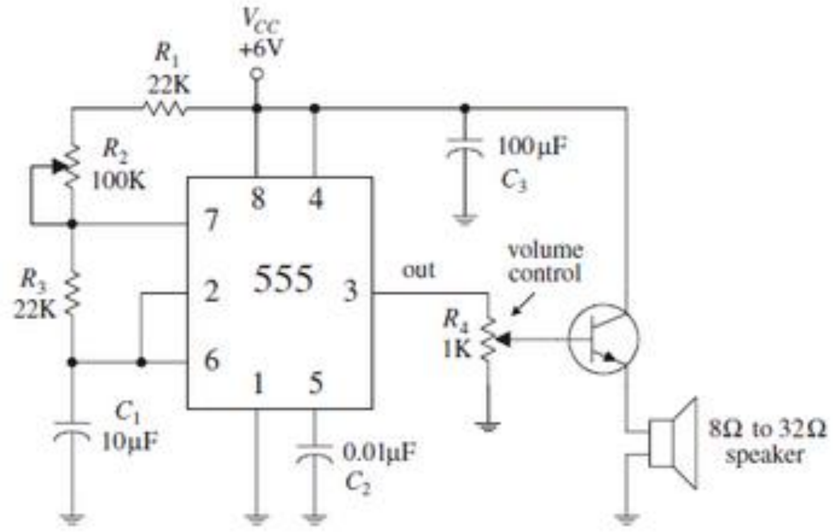
555 Applications: Metronome

- Circuit is an oscillator circuit (astable multivibrators)



- metronome circuit produces a series of "clicks" at a rate determined by R_2. To control the volume of the clicks, R_4 can be adjusted.

Crystal Oscillators

- We have none in ECTE250
- But these are very often used to generate very stable clocks
- So (provided its not for the heart beat circuit – that must be a NE555 timer) I could order some crystals for your projects in ECTE250 if you can justify their use in your teams design!

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Crystal Oscillators

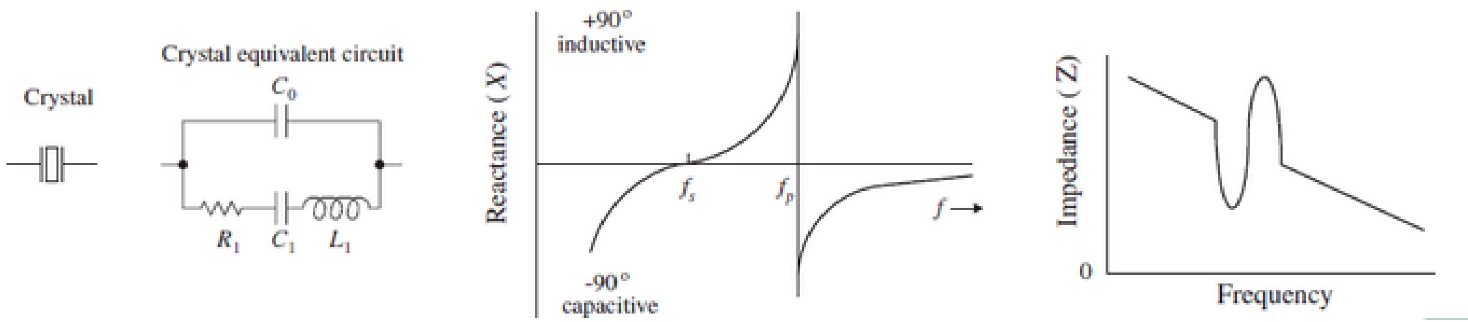
- When stability and accuracy become critical in oscillator design—which is often the case in high-quality radio and microprocessor applications—one of the best approaches is to use a crystal oscillator.
- The stability of a crystal oscillator (from around 0.01 to 0.001 percent) is much greater than that of an *RC* oscillator (around 0.1 percent) or an *LC* oscillator (around 0.01 percent at best) {see ECTE212 for examples of these and other sections of chapter 10 of practical electronics for inventors}
- When a quartz crystal is cut in a specific manner and placed between two conductive plates that act as leads, the resulting two-lead device resembles an *RLC* tuned resonant tank (essentially a second order circuit).
- When the crystal is shock-excited by either a physical compression or an applied voltage, it will be set into mechanical vibration at a specific frequency and will continue to vibrate for some time, while at the same time generating an ac voltage between its plates.
- This behavior, better know as the *piezoelectric effect,*

Crystal Oscillators

- It is similar to the damped electron oscillation of a shock-excited *LC* circuit.
- unlike an *LC* circuit, the oscillation of the crystal after the initial shock excitation will last longer—a result of the crystal's naturally high Q value (for the equivalent RLC tank circuit!)
- For a high-quality crystal, a Q of 100,000 is not uncommon whereas *LC* circuits typically have a Q of around a few hundred.

Crystal Oscillators

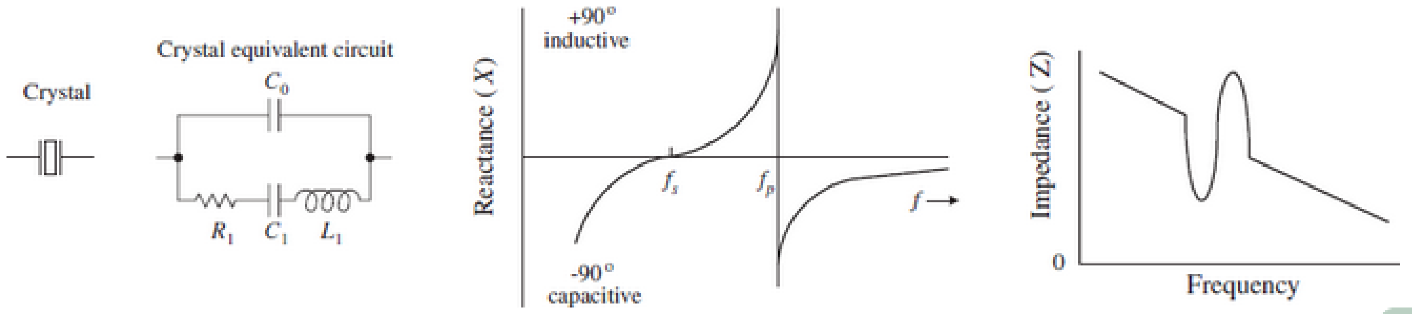
- This RLC circuit can be used as an equivalent circuit for a crystal:



- The lower branch of the equivalent circuit, consisting of R_1, C_1, and L_1 in series, is called the *motional arm*.
- The motional arm represents the series mechanical resonance of the crystal.
- The upper branch containing C_0 accounts for the stray capacitance in the crystal holder and leads.

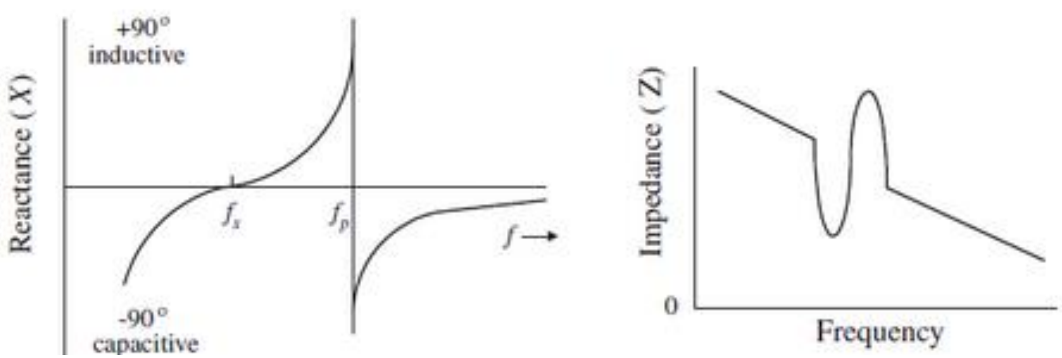
Crystal Oscillators

- The *motional inductance* L_1 is usually many henries in size, while the motional capacitance C_1 is very small (<<1 pF).
- The ratio of L_1 to C_1 for a crystal is much higher than could be achieved with real inductors and capacitors.
- Both the internal resistance of the crystal R_1 and the value of C_0 are both fairly small:
  - For a 1-MHz crystal, the typical components values within the equivalent circuit would be L_1 = 3.5 H, C_1 = 0.007 pF, R_1 = 340 Ω, C_0 = 3 pF
  - For a 10-MHz fundamental crystal, the typical values would be L_1 = 9.8 mH, C_1 = 0.026 pF, R_1 = 7 Ω, C_0 = 6.3 pF



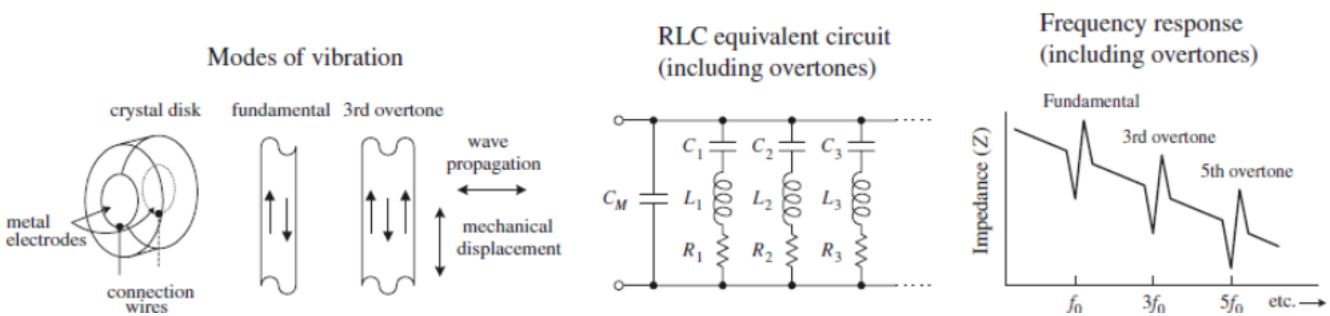
Crystal Oscillators

- a crystal can be driven at *series resonance* or *parallel resonance*.
- In series resonance, when the crystal is driven at a particular frequency, called the *series resonant frequency* f_s, the crystal resembles a series-tuned resonance *LC* circuit; the impedance across it goes to a minimum—only R_1 remains.
- In parallel resonance, when the crystal is driven at what is called the *parallel resonant frequency* f_p, the crystal resembles a parallel-tuned *LC* tank; the impedance across it peaks to a high value:



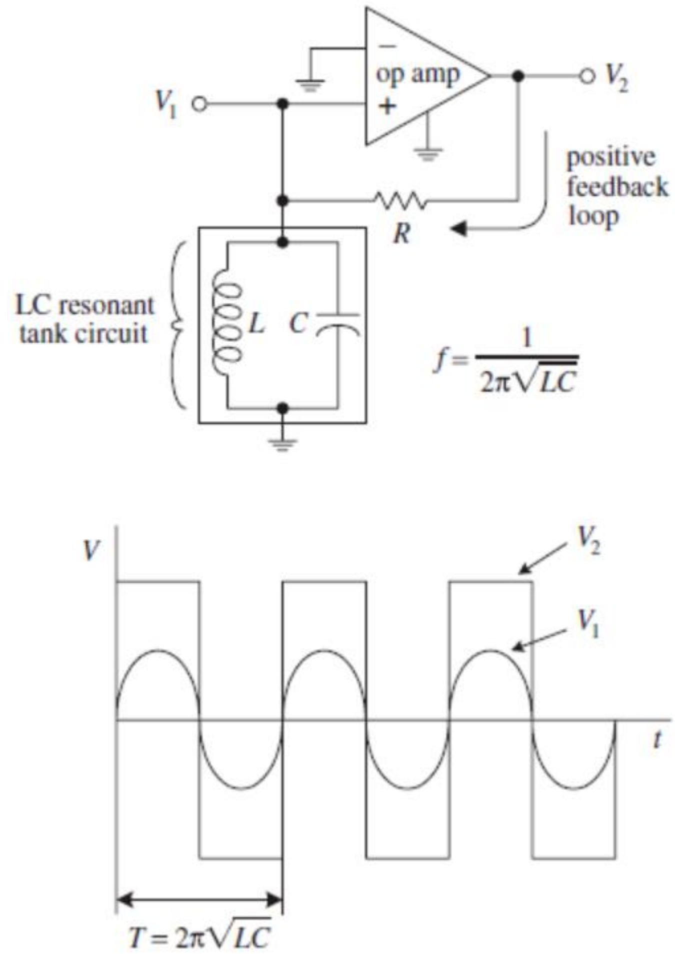
Crystal Oscillators

- Quartz crystals come in series-mode and parallel-mode forms and may either be specified as a fundamental-type or an overtone-type crystal.
- Fundamental-type crystals are designed for operation at the crystal's fundamental frequency, while overtone-type crystals are designed for operation at one of the crystal's overtone frequencies/odd integer harmonic frequencies of the fundamental ($3f_o$, $5f_o$ etc..).
- Fundamental-type crystals are available from around 10 kHz to 30 MHz, while overtone-type crystals are available up to a few hundred megahertz.



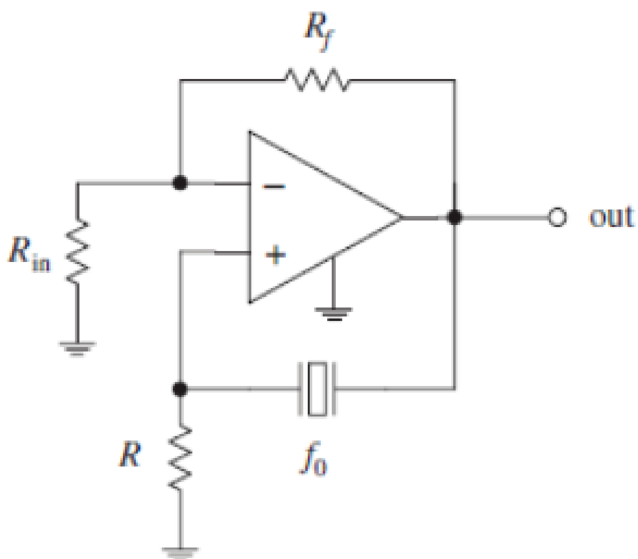
LC Oscillator

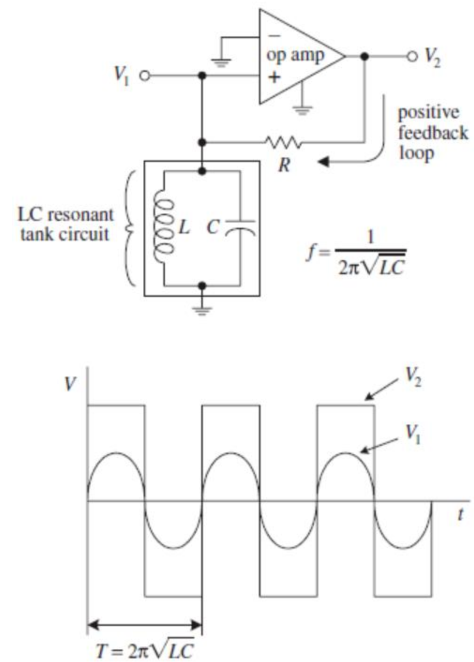
LC oscillators basically consist of an amplifier that incorporates positive feedback through a frequency-selective *LC* circuit (or Tank). The *LC* tank acts to eliminate from the amplifier's input any frequencies significantly different from its natural resonant



Crystal Oscillators: Basic Crystal Oscillator Circuit using op-amp

- Designing crystal oscillator circuits is similar to designing *LC* oscillator circuits, except that now you replace the *LC* tank with a crystal. The crystal will supply positive feedback and gain at its series or parallel resonant frequency, hence leading to sustained oscillations.
- The simple op amp circuit shown here (below on left) resembles the *LC* oscillator circuit (below on right), except that it uses the series resonance of the crystal instead of the parallel resonance of an *LC* circuit to provide positive feedback at the desired frequency.





Crystal Oscillators

- There are a number of ICs available that can make designing crystal oscillators a breeze.
- Some of these ICs, such as the 74S124 TTL VCO (square wave generator), can be programmed by an external crystal to output a waveform whose frequency is determined by the crystal's resonant frequency.
- The MC12060 VCO (Voltage Controlled Oscillator), unlike the 74S124, outputs a pair of sine waves.
- there are also crystal oscillator modules that contain everything (crystal and all) in one single package.
- These modules resemble a metal-like DIP package, and they are available in many of the standard frequencies (e.g., 1, 2, 4, 5, 6, 10, 16, 24, 25, 50, and 64 MHz, etc.)
- Check the electronic catalogues to see what other types of oscillator ICs are available if interested

Passive Sensors

- Most passive sensors (transducers) are variable passive components (mostly resistors)

- A physical quantity (e.g. light, temperature, force, etc.) can be measured inserting the sensor in a proper circuit and reading an analog voltage using an ADC
  - Physical Quantity → Resistance Value (Sensor)
  - Resistance Value → Voltage (Circuit)
  - Analog Continuous Voltage → Discrete Digital Value (i.e. number) (ADC)

- If you need to convert the ADC out back to the Physical quantity you need to trace back each conversion stage (often non linear!)

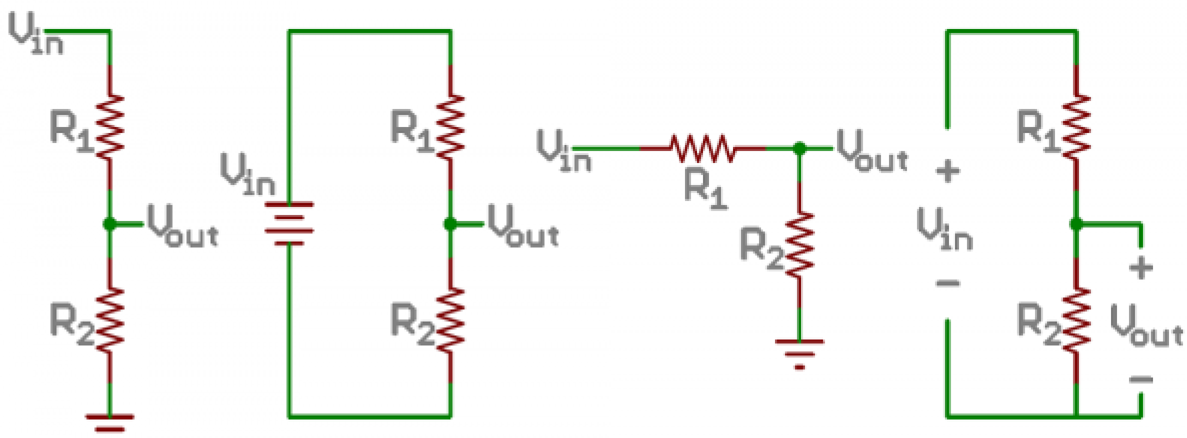
Sensors Circuits

- Common for sensors acting as a variable resistor are
  - Voltage Divider (require ADC)
  - Wheatstone Bridge (requires ADC)
  - Step Response Technique (RC timing circuit, does not require ADC)

- If you need to convert the ADC out back to the Physical quantity you need to trace back each conversion stage (often non linear!)

Sensors Circuits

- Voltage Divider
- ADC usually read values between GND and a Positive Reference Voltage



$$V_{out} = V_{in} \cdot \frac{R_2}{R_1 + R_2}$$

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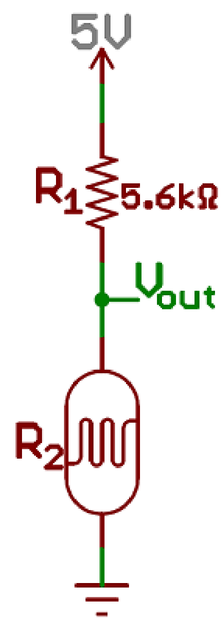
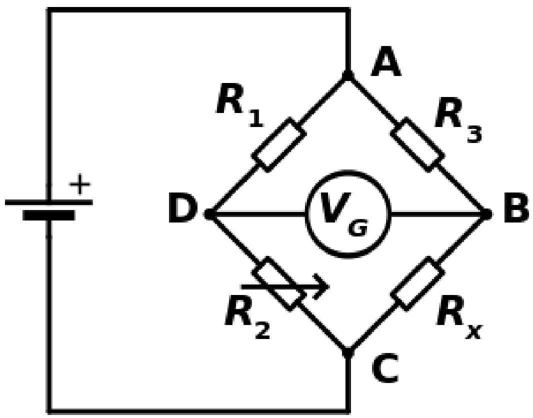
Sensors Circuits

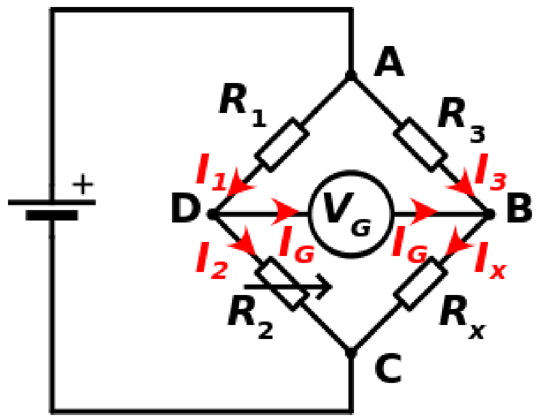
- Voltage Divider Example - photocell
- The photocell's resistance varies between 1kΩ in the light and about 10kΩ in the dark. If we combine that with a static resistance somewhere in the middle - say 5.6kΩ, we can get a wide range out of the voltage divider they create.



Sensors Circuits

- A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance (Ohmmeter).
- It works by balancing two legs of a bridge circuit, one leg of which includes the unknown component.
- When R2 is equal to Rx Vg=0.





$$V_G = \left(\frac{R_2}{R_1 + R_2} - \frac{R_x}{R_x + R_3} \right) V_s$$

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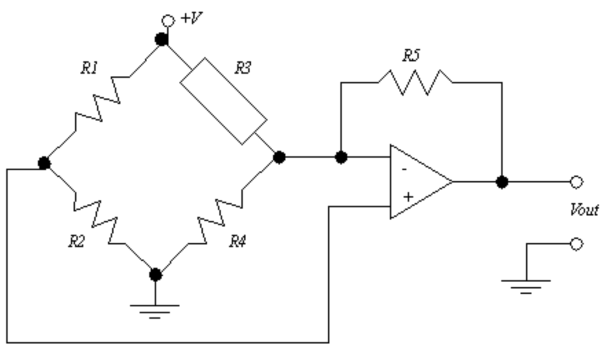
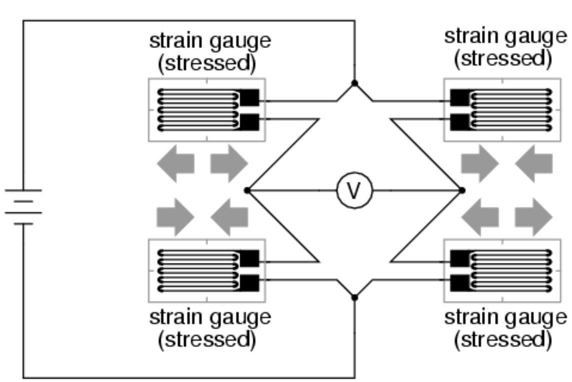
Sensors Circuits

- If you use 3 fixed resistors, you should remove the V bias at one side of the bridge
- If the voltage difference is too small you can use an inverting op-amp.



- Wheatstone bridges are useful when you want to measure 2 or more variable resistors (e.g. load cells, strain gauges)



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Sensors Circuits

- Step Response Technique (RC timing circuit, does not require ADC)

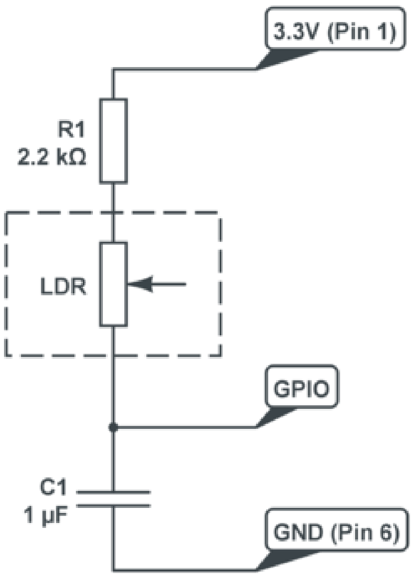
- Useful When you do not have an ADC.

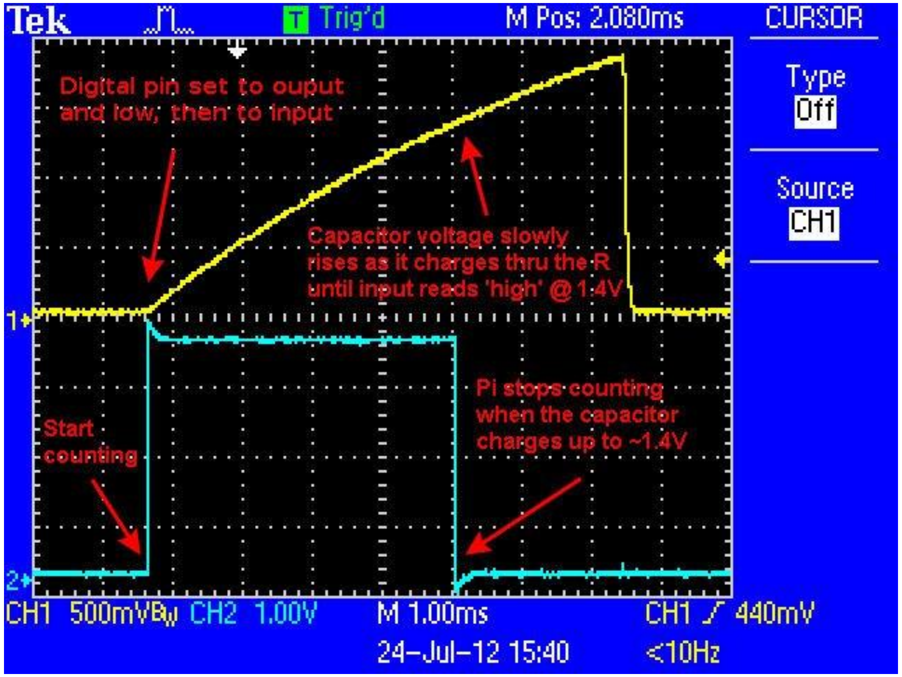
- It works by seeing how a RC (resistor-capacitor) circuit responds to an electrical pulse switching from a low to high signal transition within a specified time frame.

- The electrical response behavior of the RC circuit is based on the charging and discharging of the capacitor receiving an electrical pulse or step signal.

Sensors Circuits

- Set GPIO to OUTPUT and LOW (discharge capacitor)
- Then set GPIO to INPUT and measure the time it takes to het HIGH
- The time is proportional to the variable resistor
- You have to consider what is the minimum voltage considered as high





Acknowledgement

- Peter Vial, UOW; Stefano Fasciani, Oslo University