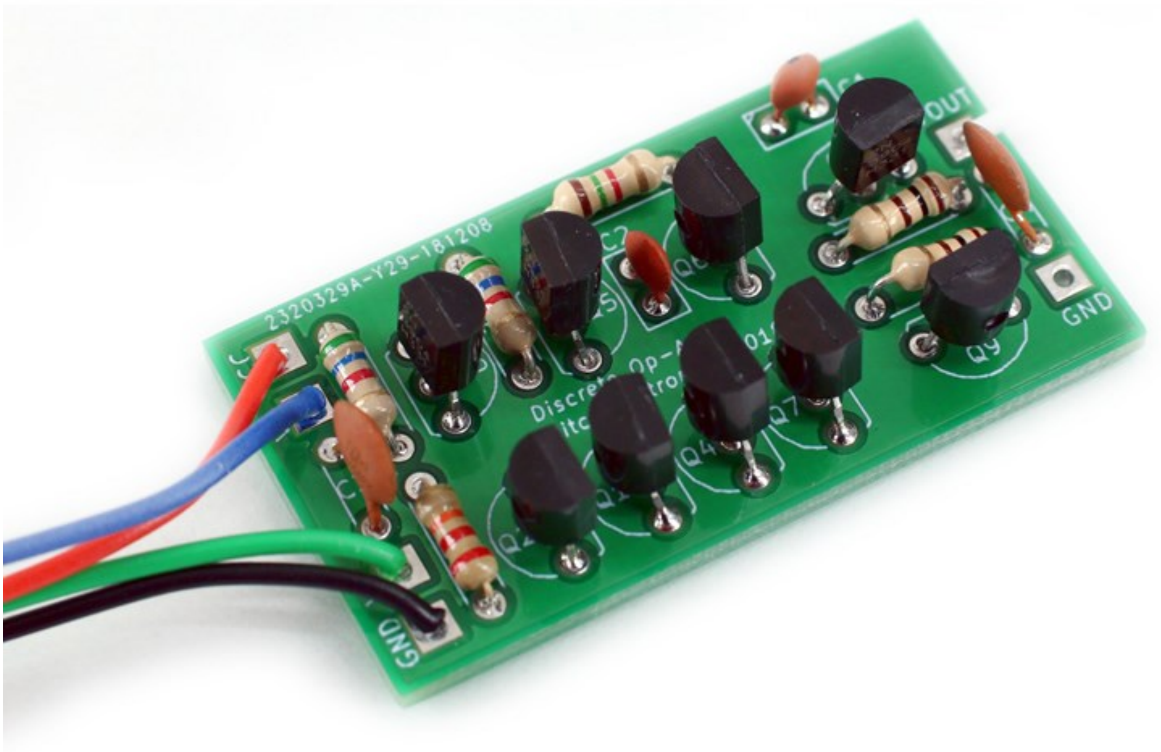
Discrete Op-Amp Kit

MitchElectronics 2019



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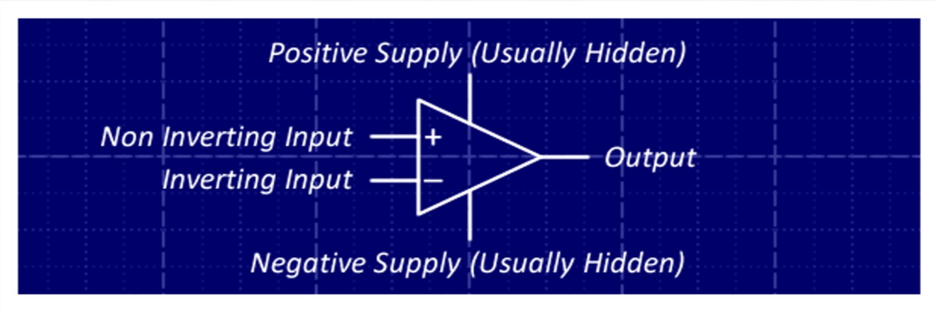
INTRODUCTION

Even if you are new to electronics, you most likely have used an op-amp. If not, an op-amp stands for operational amplifier and has the symbol shown below.



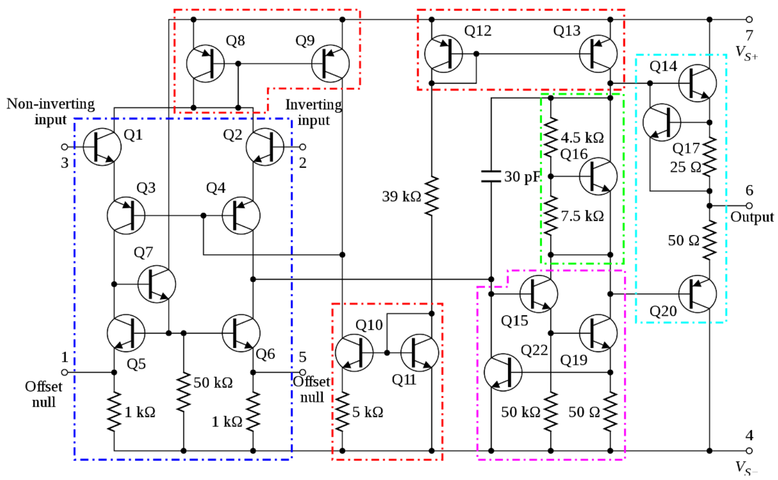
The op-amp has two inputs (+ and -), two power pins and a single output. While the maths behind op-amp circuits can be complex the basic formula that shows the output voltage is given as:

$$V_{Out} = A(V_{NonInverting} - V_{Inverting})$$

$$V_{Out} = A(V_{+} - V_{-})$$

Where A is very large (>100000)

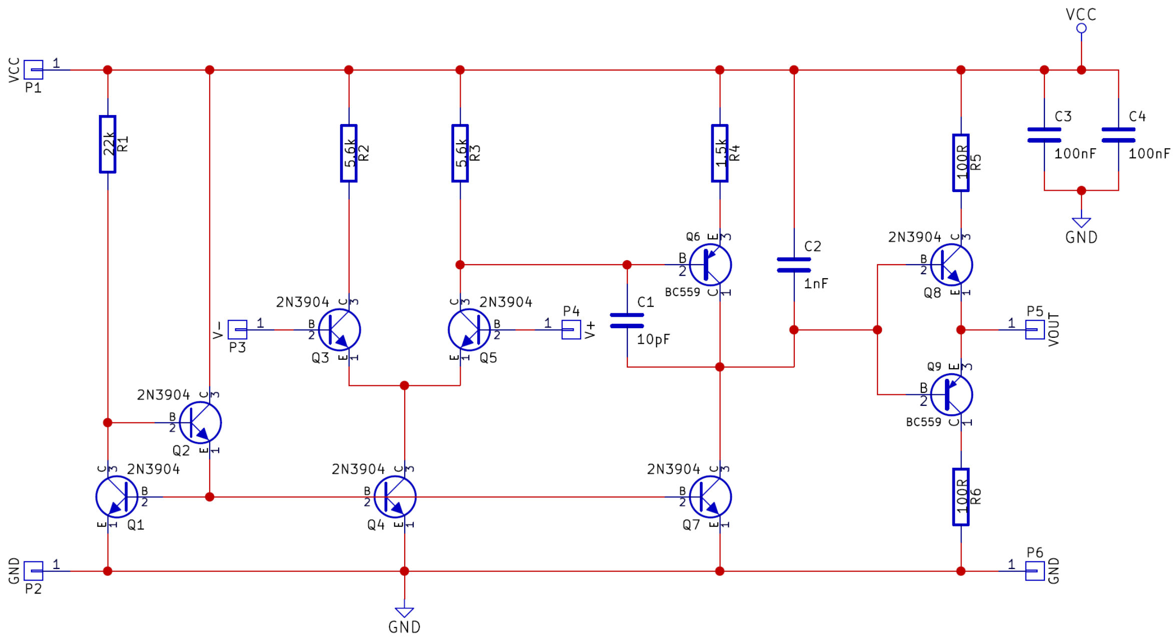
By using a combination of other components the op-amp can be used to make many different circuits ranging from amplifiers to oscillators. But op-amps that you typically use in a circuit are in a small plastic package and to most are considered black boxes (something that just works). An example of a famous op-amp, the 741, is shown below with its schematic.



commons.wikimedia.org/wiki/File:OpAmpTransistorLevel_Colored_Labeled.svg

But this kit will not only let you build your own basic op-amp but will also teach you the basics of how they actually work!

SCHEMATIC


VCC
P1
GND
P2
22k
R1
5.6k
R2
5.6k
R3
1.5k
R4
100R
R5
100R
R6
C1
10pF
C2
1nF
C3
100nF
C4
100nF
2N3904
Q1
Q2
Q3
Q4
Q5
Q6
BC559
Q7
Q8
Q9
V-
P3
V+
P4
P5
VOUT
P6
GND

SCHEMATIC EXPLANATION

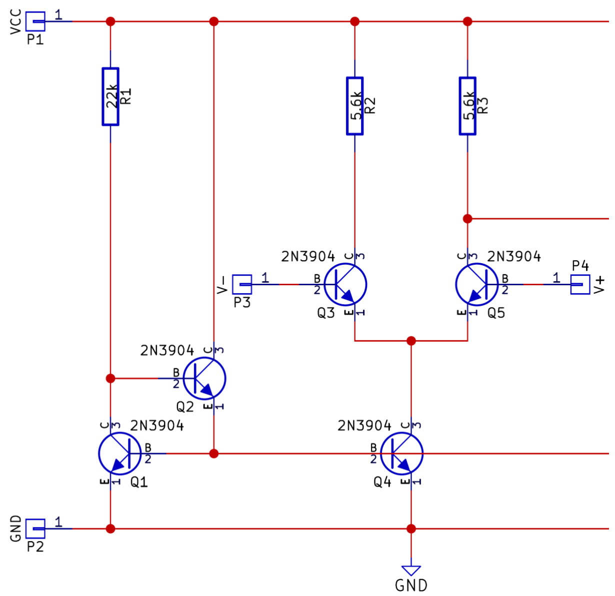
The op-amp consists of several stages:

- Q3, Q4 and Q5 form the input stage
- Q1 and Q2 form a constant current source (keeps Q4 and Q7 current constant)
- Q6 forms an amplifier to increase the open loop gain of the op amp
- Q8 and Q9 consist of a push pull amplifier which is the output stage

Input Stage

If both input voltages are the same both Q3 and Q5 will conduct the same current. If the V+ input (Q5) increases then Q5 will be able to conduct more current and as a result does. So now that more current is flowing through Q5 means that the current flowing through Q3 needs to reduce. This is because Q4 can only conduct a limited amount of current (controlled by the current mirror Q1 and Q2), and so if more current flows through Q5 then less current flows through Q3 which leaves the current in Q4 unchanged. Since the effective resistance of Q5 has been reduced (as it is now conducting more), the voltage at the collector of Q5 decreases.

If the voltage on V- (Q3), increases then the same will happen as before except the current through Q3 will increase and the current through Q5 will decrease since the total current that can be conducted is limited by Q4. Since Q5 now conducts less its effective resistance has increased and thus the voltage at the collector of Q5 increases.



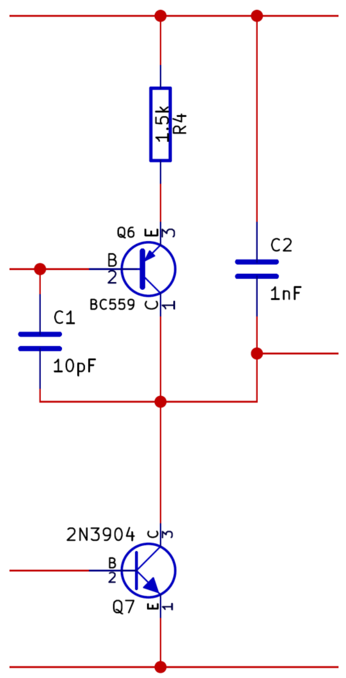
SCHEMATIC EXPLANATION

Amplification Stage

The output of the input stage (Q5 collector), is fed into a PNP transistor (Q6), which has an NPN transistor (Q7), acting as a resistor. If the input voltage to this stage increases then the output of the amplifier (Q6 collector), will decrease. This is because an increase in the input voltage makes the base-emitter region of the PNP transistor more positive which results in the PNP transistor conducting less. When Q6 conducts less the voltage drop across the active load (Q7), will therefore also drop.

If the output from the input stage decreases then the base-emitter voltage of Q6 will become more negative (as the emitter is at a larger positive voltage than the base), and thus Q6 will conduct more. The current through the active load will therefore increase and result in a larger voltage drop across Q7.

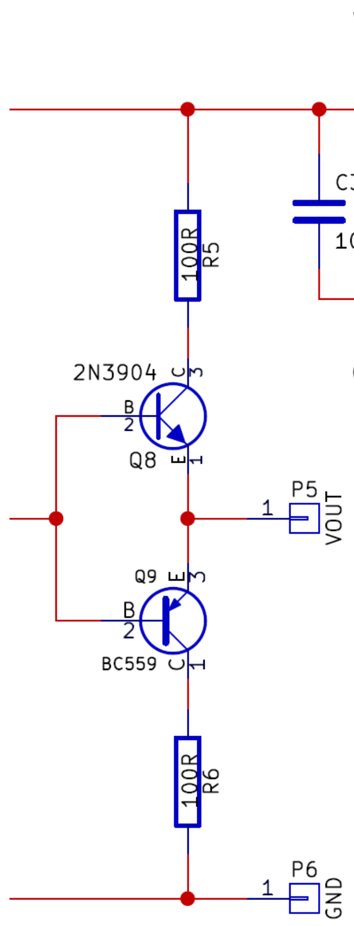
C1 is a very special capacitor which stops oscillations. It has a very specific name, a miller capacitor. The miller effect is complex to understand but simply put the capacitor ensures that the gain of the op-amp falls below 1 before the phase shift reaches 180 degrees.



SCHEMATIC EXPLANATION

Output Stage

The output stage consists of a push pull amplifier (Q8 and Q9), with current limiting resistors (R5 and R6). The input to the output stage is connected to the output of the amplifier stage. Simply put, if the input to the output stage increases then the output voltage will increase. If the input voltage decreases then the output voltage will be lower.



SCHEMATIC EXPLANATION

So now that we have looked at each part let's run through the whole design again briefly to fully understand the nature of op-amps!

An increase in V+

1. Q5 conducts more and thus Q3 conducts less
2. Voltage across Q5 collector therefore reduces
3. Amplifier stage is inverting and a reduction in the input results in a larger output
4. This increase in output voltage is passed to the push-pull amplifier
5. The output voltage increases

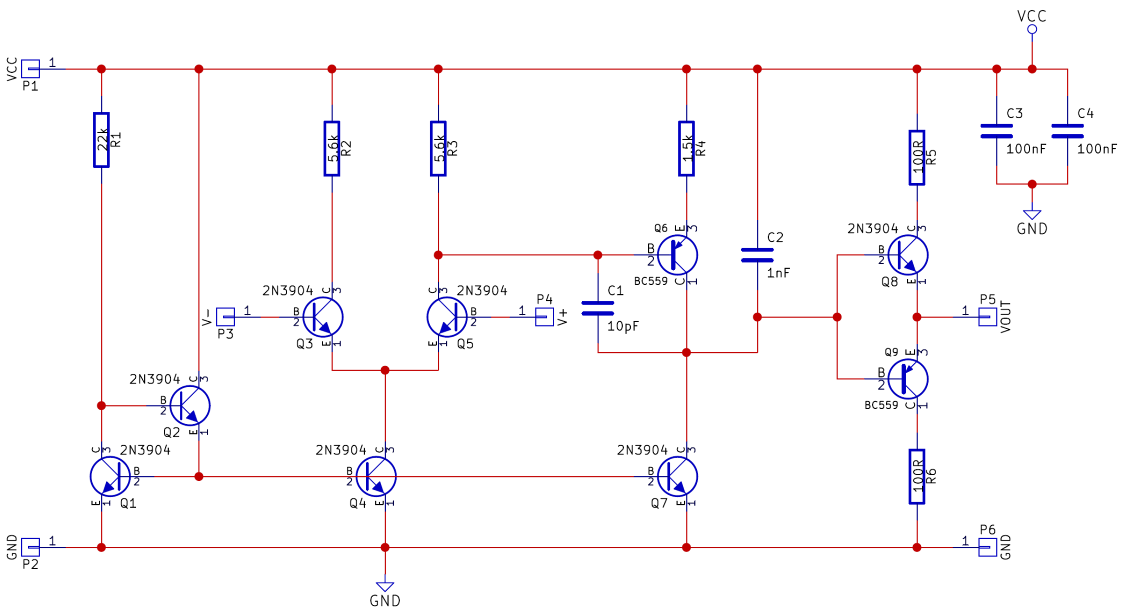
An increase in V-

1. Q3 conducts more and thus Q5 conducts less
2. Voltage across Q5 collector therefore increases
3. Amplifier stage is inverting and an increase in the input results in a smaller output
4. This decrease in output voltage is passed to the push-pull amplifier
5. The output voltage decreases

Here are some ideas that you can try with your op-amp:

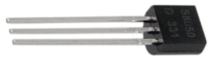
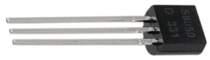
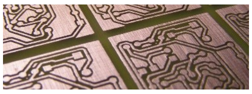
1. Connect V- to the output pin and slowly increase the input voltage
2. Create an inverting and non-inverting amplifier using resistors
3. Try creating a simple RC oscillator

Note: If using feedback do not use resistors larger than 1kΩ! That's right, do not use larger because the op-amp needs a decent amount of input current!



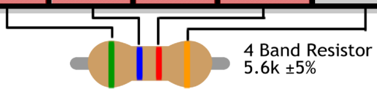
MATERIALS

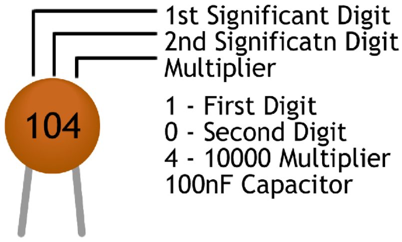
Check that you have the following components

Component	Component Name	Quantity	Looks like
BC559 (Or BC557 or BC558)	Q6, Q9	2	
2N3904	Q1, Q2, Q3, Q4, Q5, Q7, Q8	7	
10pF Capacitor	C1	1	
1nF Capacitor	C2	1	
100nF Capacitor	C3, C4	2	
22kΩ Resistor	R1	1	
5.6kΩ Resistor	R2, R3	2	
1.5kΩ Resistor	R4	1	
100Ω Resistor	R5, R6	2	
Wire	Red, Green	1	
Wire	Black, Blue	2	
PCB	-	1	

RESISTOR AND CAPACITOR IDENTIFICATION

Colour	1ST Band	2ND Band	3RD Band	Multiplier	Tolerance
BLACK	0	0	0	1Ω	
BROWN	1	1	1	10Ω	±1%
RED	2	2	2	100Ω	±2%
ORANGE	3	3	3	1kΩ	
YELLOW	4	4	4	10kΩ	
GREEN	5	5	5	100kΩ	±0.50%
BLUE	6	6	6	1MΩ	±0.25%
VIOLET	7	7	7	10MΩ	±0.10%
GREY	8	8	8		±0.05%
WHITE	7	7	7		
GOLD					±5%
SILVER					±10%





CONSTRUCTION

Download the electronics construction manual

To learn how to construct circuits on PCBs download the Electronics Construction Manual from Mitch-Electronics using the link below. This document shows you how to install all electronic components used in MitchElectronics kits. The list below shows the sections relevant to this kit so do not worry if you see component sections in the document that don't come with this kit!

www.mitchelectronics.co.uk/electronicsConstructionManual.pdf

Relevant sections in the electronics construction manual

Resistors

Capacitors

Transistors

Wires

IMPORTANT INFORMATION

RoHS Compliant Kit (Lead free)

Low Voltage Kit

Caution! Soldering Required