Ins and Outs of Op Amps

Simple explanation without complex mathematics

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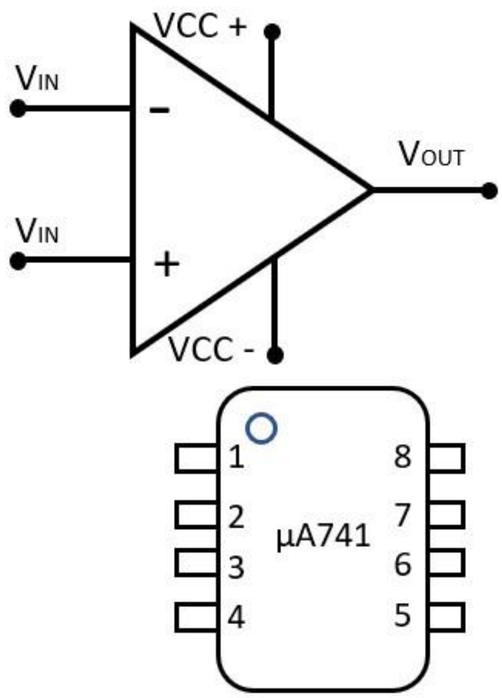
The operational amplifier (Op Amp) is one of the most versatile devices available, and applications using this device are widespread in both the analogue and digital arenas. The vacuum tube Op Amp was invented by Karl Dale Swartzel Jr (1907 – 1998) in 1941 when working at Bell Laboratories.

Looking at the Op Amp as a black box, there are usually five connections. The symbol for the Op Amp is a sideways triangle (Figure 1).

In some drawings, the power connections are not shown, but implied.



Pin Name	Description	µA741 Pin
VIN -	Inverting input. Output will be 180 degrees out of phase with the input.	2
VIN +	Non inverting input. Output will be in phase with the input.	3
VCC +	Positive supply voltage	7
VCC -	Negative supply voltage	4
VOUT	Output to the next stage.	6
Offset N1	External offset voltage adjustment. (Not shown)	1
Offset N2	External offset voltage adjustment. (Not shown)	5

µA741 Pin 8 is not connected.

Figure 1: Op Amp connections.

Offset

Unavoidable mismatches in the Op Amp circuitry can cause the device to output a signal when then is no input signal. These input mismatches can be adjusted as per the datasheet for the Op Amp in use. Usually by applying an offset voltage to N1 and/or N2.

Op Amp Configurations

<u>Open Loop</u> – In the open loop configuration the Op Amp gain is so great it is not effective as an analogue amplifier. This configuration is ideal to use the Op Amp as a comparator or switch.

<u>Closed Loop</u> – The closed loop amplifier has feedback applied to the input. The feedback components control the gain of the amplifier.

Ideal Op Amp Characteristics

Open Loop Gain (Avo) – The ideal Op Amp has high gain of about 20,000 to 200,000. Feedback is applied to control the Op Amp gain.

Input impedance (Z_{IN}) – The input impedance is the ratio of input voltage to input current and is assumed to be infinite.

Output impedance (Z_{OUT}) - The output impedance of the ideal operational amplifier is assumed to be zero, but in reality, the output impedance is in the 100 Ω-20 kΩ range.

Bandwidth (BW) - An ideal operational amplifier has an infinite frequency response from DC to daylight, so it has infinite bandwidth. In real Op Amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifier's gain becomes one.

Common Mode Rejection Ratio (CMRR) - CMRR is the ability of the Op Amp to reject the same signal on both inputs. This is import for the cancellation of noise common to both inputs.

Offset Voltage (V_{IO}) – The Op Amp output is zero when the voltage difference between the inverting and the non-inverting inputs is zero. Real Op Amps have some amount of output offset voltage.

These ideal characteristics can be summarized by the very important Golden Rules:

1. In a closed loop configuration, the output drives the V_{IN} + and V_{IN} – to be equal.
2. The inputs draw no current.

Typical Op Amp

A very common Op Amp is the µA741 (Figure 1). Below are a few interesting figures from the µA741 data sheet that make it a versatile device.

- V_{CC+} Supply maximum +15 V
- V_{CC-} Supply maximum -15 V
- Vom Output voltage swing typically +/-14 V
- Icc No load supply current 3.3 mA
- T_A Operating free-air temperature maximum 70° C
- CMRR Typically 90 dB
- r_i Input resistance typically 2 MΩ
- r_o Output resistance typically 75 Ω

Useful Op Amp Circuits

There are many circuits using the Op Amp as the primary component. I selected 10 to provide examples.

1. The Voltage Follower, also known as a unity gain amplifier, buffer amplifier, or isolation amplifier. This circuit is used as a buffer because it draws very little current due to the high input impedance of the amplifier, which eliminates loading effects on the preceding input circuit. The Op Amp has a gain of 1 so the output is the same as the input (Figure 2). **TIP:** Review the Golden Rules.

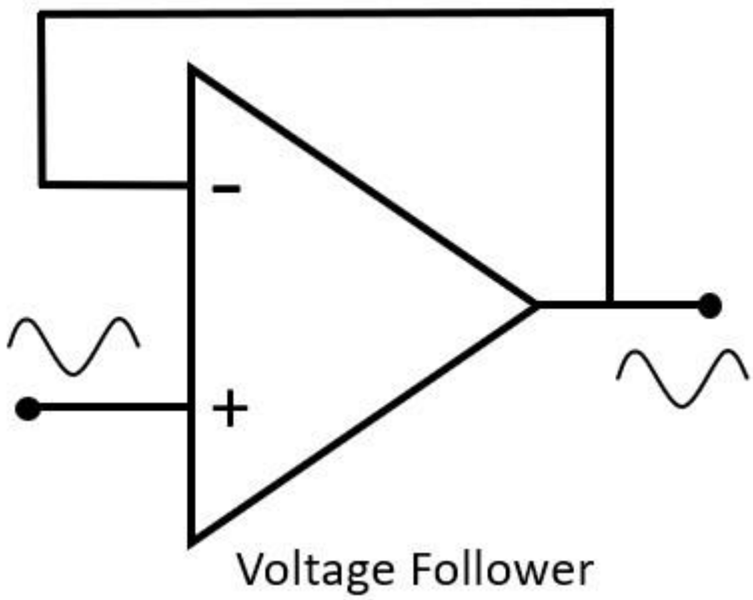


Figure 2: Voltage Follower.

2. The Inverting amplifier changes the signal by 180 degrees. The gain of the amplifier is determined by the ratio of R_1 and R_2 (Figure 3).

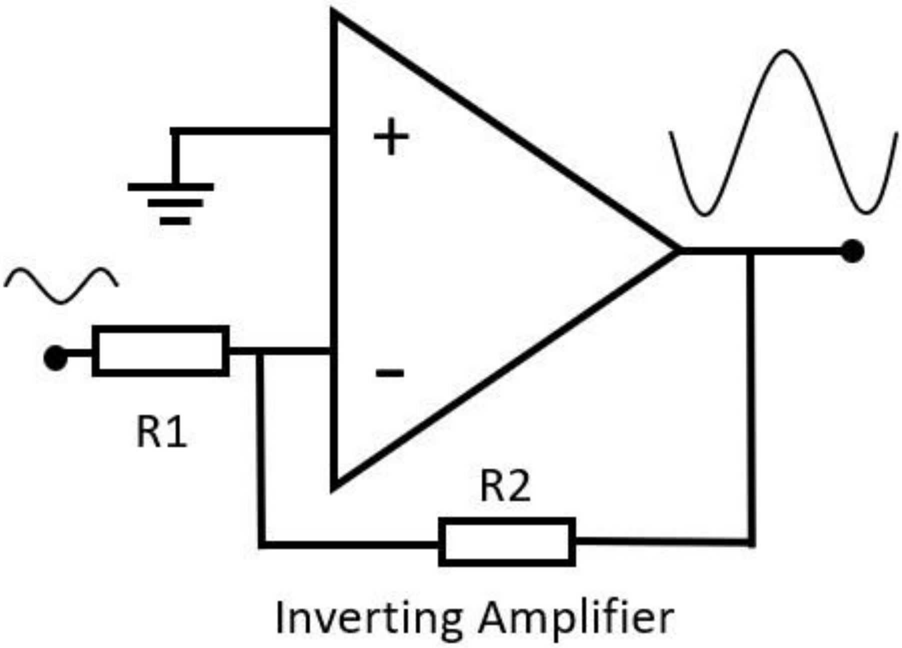


Figure 3: Inverting amplifier.

3. The Non-inverting amplifier is used where the input and output are in phase. The gain of the amplifier is determined by the ratio of R_1 and R_2 (Figure 4).

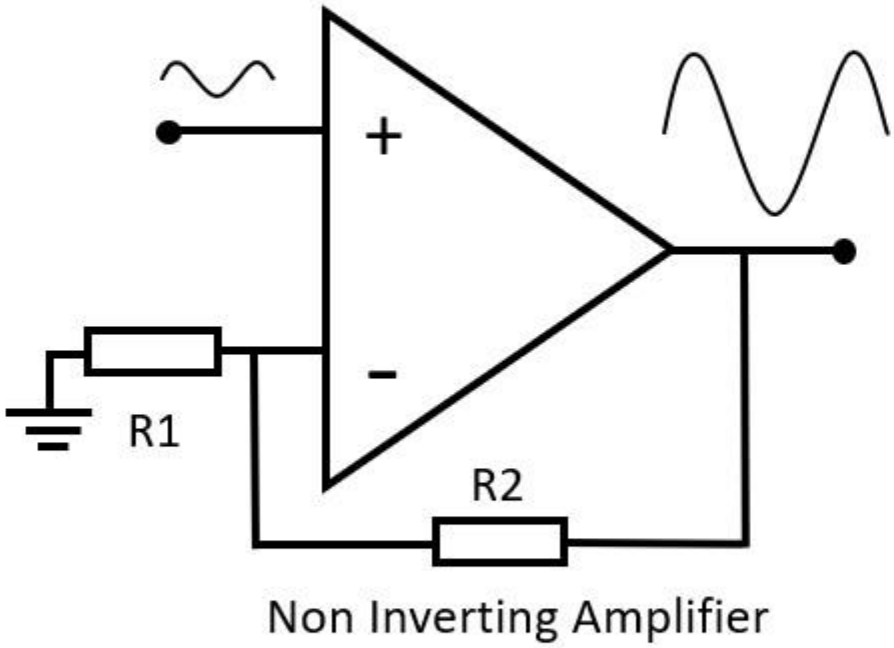


Figure 4: Inverting amplifier.

4. The Non-inverting summing amplifier is used to combine the voltages present on two or more inputs into a single output voltage. As it is noninverting, the output will be in phase with the input. The gain of the amplifier is determined by the ratio of R_1 and R_2 (Figure 5).

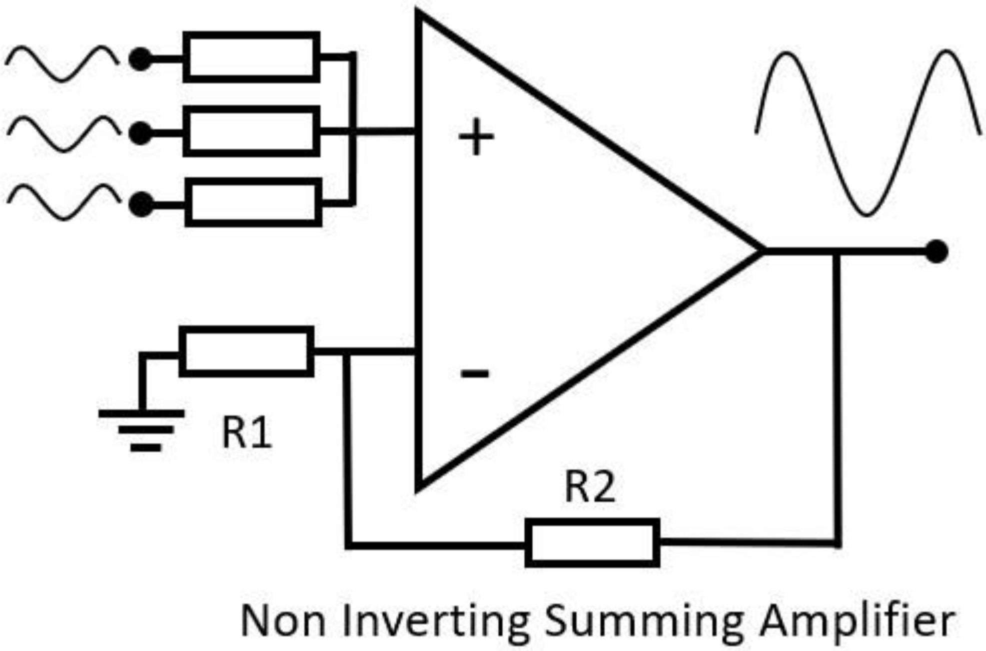


Figure 5: Non-inverting summing amplifier.

5. The Differential amplifier is a circuit that amplifies the difference between two input voltages but suppresses any voltage common to the two inputs. The circuit has two inputs, and the output is proportional to the difference between the two voltages (Figure 6).

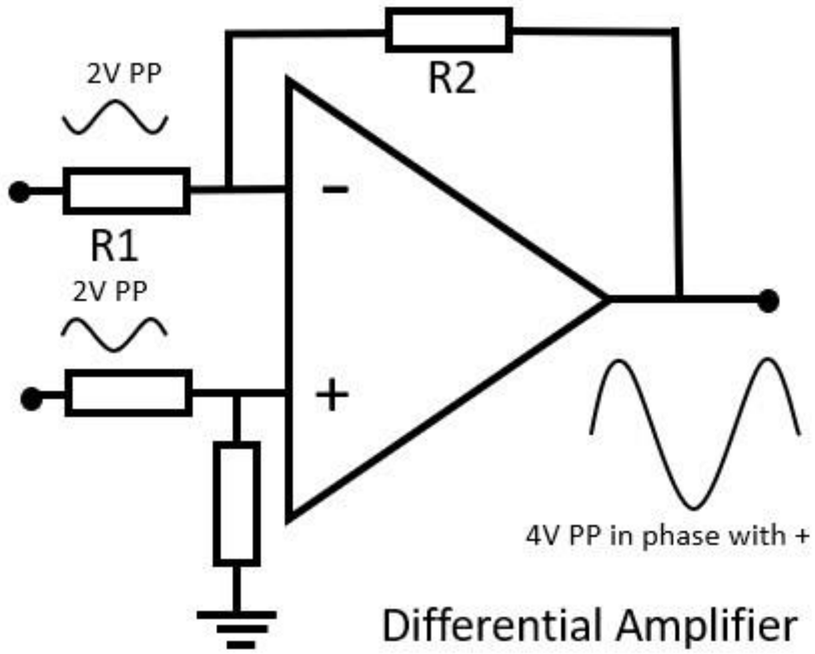


Figure 6 : Differential amplifier.

6. The Integrator Op Amp performs integration with respect to time. The output is proportional to the input voltage integrated over time governed by R_1 and C_1 (Figure 7).

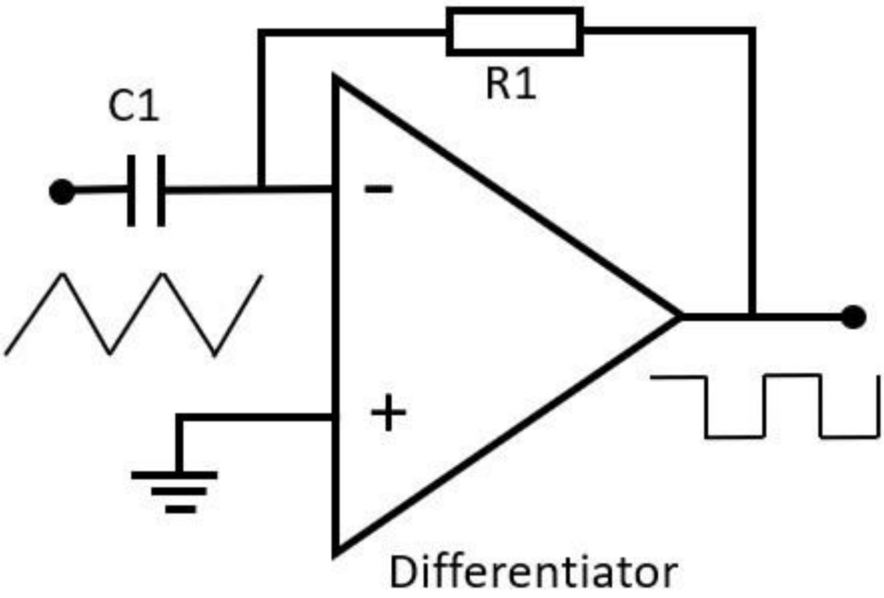


Figure 7: Integrator.

7. The Differentiator is designed so the output of the circuit is proportional to the rate of change to the input. The rate of change is governed by C_1 and R_1 (Figure 8).

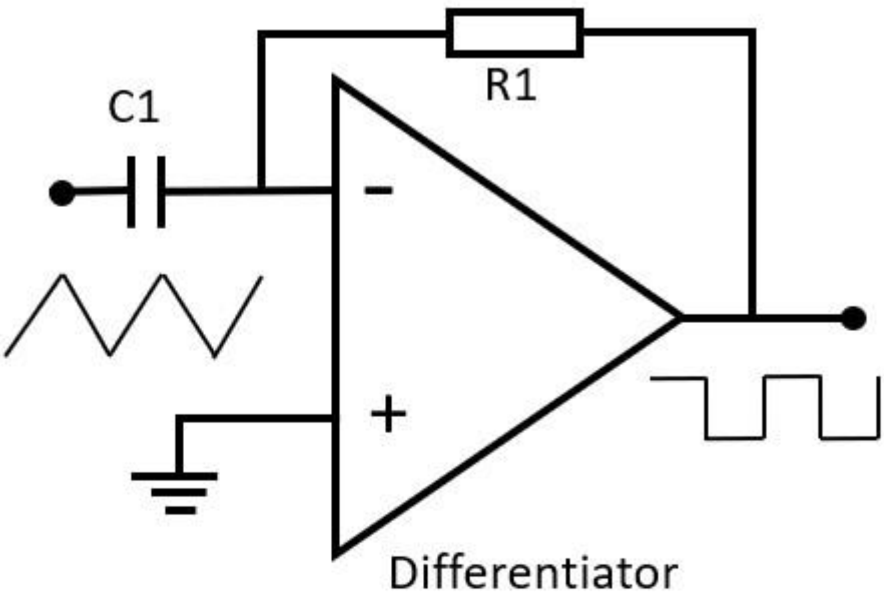


Figure 8: Differentiator.

8. THE High pass filter is a unity gain amplifier passing the frequencies higher than that determined by R_1 and C_1 (Figure 9).

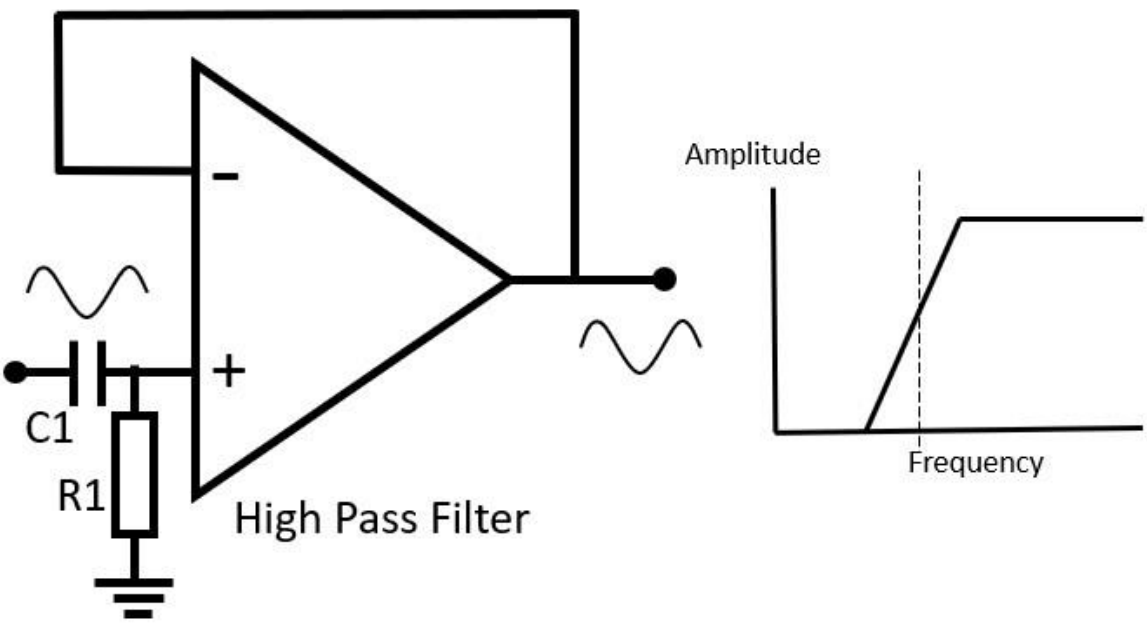


Figure 9: High Pass Filter.

9. The Low pass filter is a unity gain amplifier passing the frequencies lower than that determined by R_1 and C_1 (Figure 10).

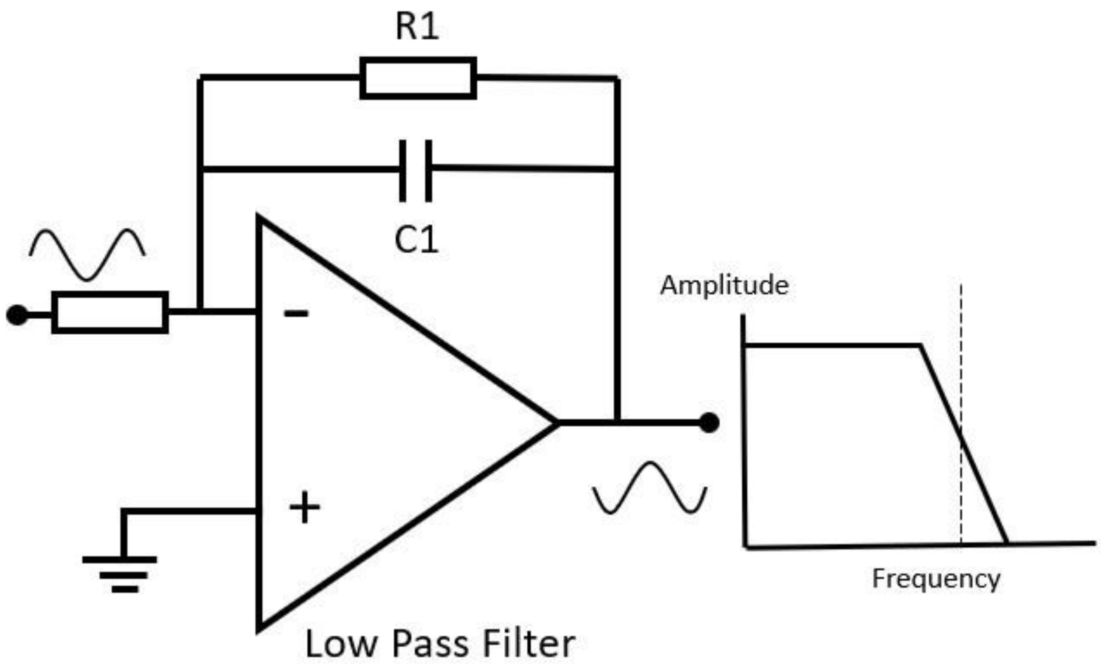


Figure 10: Low Pass Filter.

10. The Band pass filter is a unity gain amplifier. R_1 and C_1 determine the high pass cut off while R_2 and C_2 determine the low pass cut off (Figure 11).

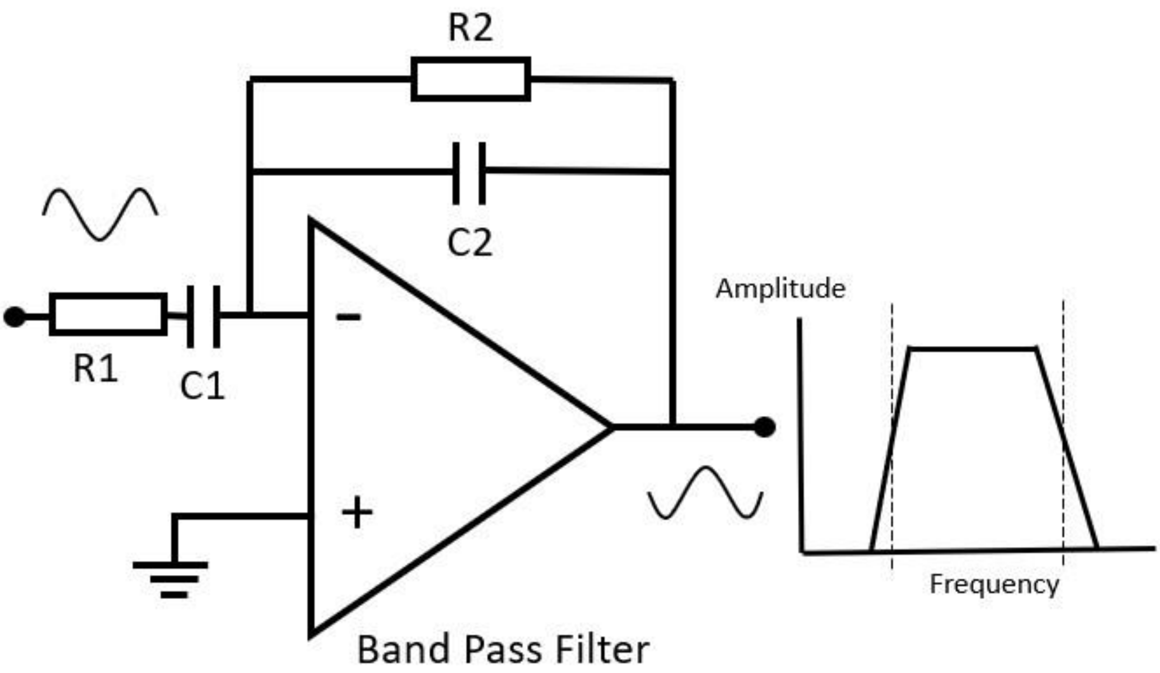


Figure 11: Band Pass Filter.

If you have a topic you would like to nominate to be covered in a future instalment of Newcomers' Notebook, email Jules at jp.bqt@bigpond.net.au

Have fun and stay safe.