



# ROHINI

## COLLEGE OF ENGINEERING & TECHNOLOGY

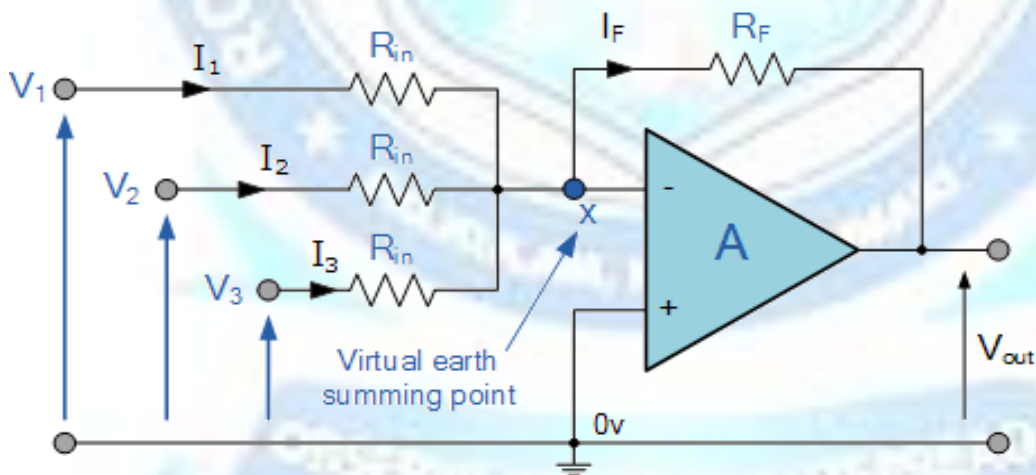
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### THE SUMMING AMPLIFIER OP-AMP CIRCUIT

We saw previously in the inverting operational amplifier that the inverting amplifier has a single input voltage, ( $V_{in}$ ) applied to the inverting input terminal. But what if we added more input resistors to the op-amps input, then we end up with another operational amplifier circuit called a **Summing Amplifier**, “*summing inverter*” or even a “*voltage adder*” circuit.

The summing amplifier circuit combines voltages from multiple inputs into one single output, which is proportional to the weighted sum of those inputs as shown below.

#### Summing Amplifier Circuit



In this simple summing amplifier circuit, the output voltage, ( $V_{out}$ ) now becomes proportional to the sum of the input voltages,  $V_1$ ,  $V_2$ ,  $V_3$ , etc. Then we can modify the original equation for the basic [inverting amplifier](#) to take account of these new extra input voltage as follows:

$$I_F = I_1 + I_2 + I_3 = - \left[ \frac{V_1}{R_{in}} + \frac{V_2}{R_{in}} + \frac{V_3}{R_{in}} \right]$$

Inverting Equation:  $V_{out} = - \frac{R_f}{R_{in}} \times V_{in}$

then,  $-V_{out} = \left[ \frac{R_F}{R_{in}} V_1 + \frac{R_F}{R_{in}} V_2 + \frac{R_F}{R_{in}} V_3 \right]$

However, if all the input impedances, ( $R_{IN}$ ) are equal in value, we can simplify the above equation to give an output voltage equal to:

### Summing Amplifier Equation

$$-V_{out} = \frac{R_F}{R_{IN}} \left( V_1 + V_2 + V_3 \dots \text{etc} \right)$$

We now have a [basic operational amplifier circuit](#) that can amplify each individual input voltage and produce one single output voltage that is proportional to the algebraic “SUM” of the three individual input voltages  $V_1$ ,  $V_2$  and  $V_3$ .

Note that we could also add more input resistors and therefore additional input voltages if required as each individual input only “sees” their respective resistance,  $R_{in}$  as their input impedance.

This is because the input signals are effectively isolated from each other by the “virtual earth” node at the inverting input of the op-amp. A direct voltage addition can also be obtained when all the resistances are of equal value and  $R_f$  is equal to  $R_{in}$ .

Note that when the summing point is connected to the inverting input of the op-amp the circuit will produce the negative sum of any number of input voltages. Likewise, when the summing point is connected to the non-inverting input of the op-amp, it will produce the positive sum of the input voltages.

### The Scaling Summing Amplifier

A **Scaling Summing Amplifier** can be made using the same summing amplifier configuration by having the individual input resistors “NOT” equal to each other. Then the equation would have to be modified to:

$$-V_{OUT} = V_1 \left( \frac{R_f}{R_1} \right) + V_2 \left( \frac{R_f}{R_2} \right) + V_3 \left( \frac{R_f}{R_3} \right) \dots \text{etc}$$

To make the math's a little easier, we can rearrange the above formula to make the feedback resistor  $R_f$  the subject of the equation giving the output voltage as:

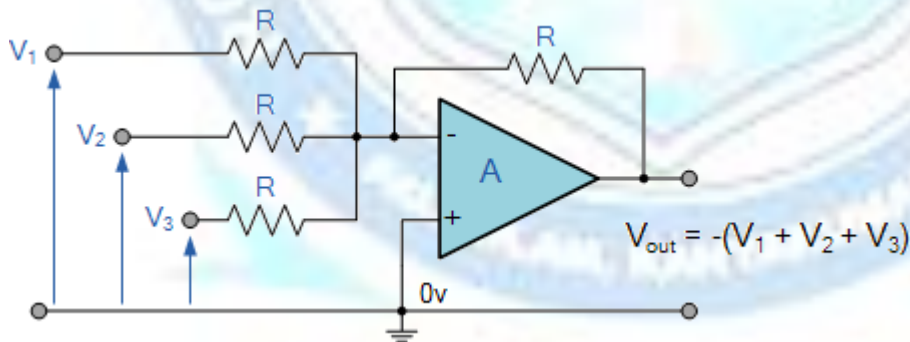
### Scaling Amplifier Feedback Equation

$$-V_{OUT} = R_f \left( \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right) \dots \text{etc}$$

This allows the output voltage to be easily calculated if more input resistors are connected to the amplifiers inverting input terminal. The input impedance of each individual channel is the value of their respective input resistors,  $R_1, R_2, R_3 \dots$  etc.

Sometimes we may want a summing circuit to just add together two or more voltage signals without any amplification. By putting all of the resistances of the circuit above to the same value  $R$ , the op-amp will have a voltage gain of unity and an output voltage equal to the direct sum of all the input voltages as shown:

### Unity Gain Summing Amplifier



Then we can see that the **Summing Amplifier** is a very flexible circuit indeed, enabling us to effectively “Add” or “Sum” (hence its name) together several individual input signals.

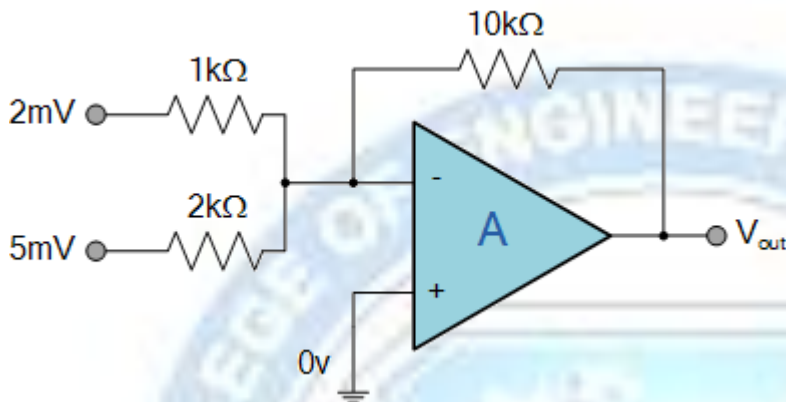
If the inputs resistors,  $R_1, R_2, R_3$ , etc. are all made equal in value it would produce a “unity gain inverting adder”.

However, if the input resistors are of different values a “scaling summing amplifier” is produced which will output a weighted sum of the input signals.

## Summing Amplifier Worked Example No1

Find the output voltage of the following *Summing Amplifier* circuit.

### The Basic Summing Amplifier Circuit



Using the previously found formula for the gain of the circuit:

$$\text{Gain } (A_v) = \frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_f}{R_{\text{in}}}$$

We can now substitute the values of the resistors in the circuit as follows:

$$A_1 = \frac{10\text{k}\Omega}{1\text{k}\Omega} = -10$$

$$A_2 = \frac{10\text{k}\Omega}{2\text{k}\Omega} = -5$$

We know that the output voltage is the sum of the two amplified input signals and is calculated as:

$$V_{\text{out}} = (A_1 \times V_1) + (A_2 \times V_2)$$

$$V_{\text{out}} = (-10(2\text{mV})) + (-5(5\text{mV})) = -45\text{mV}$$

Then the output voltage of the **Summing Amplifier** circuit above is given as **-45 mV** and is negative as its an inverting amplifier.

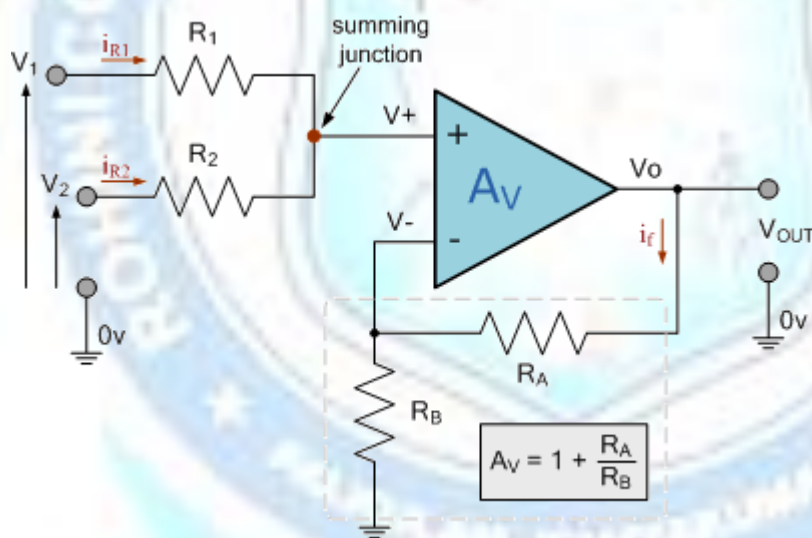
## Non-inverting Summing Amplifier

But as well as constructing inverting summing amplifiers, we can also use the non-inverting input of the operational amplifier to produce a *non-inverting summing amplifier*.

We have seen above that an inverting summing amplifier produces the negative sum of its input voltages then it follows that the non-inverting summing amplifier configuration will produce the positive sum of its input voltages.

As its name implies, the non-inverting summing amplifier is based around the configuration of a [non-inverting operational amplifier](#) circuit in that the input (either AC or DC) is applied to the non-inverting (+) terminal, while the required negative feedback and gain is achieved by feeding back some portion of the output signal ( $V_{OUT}$ ) to the inverting (-) terminal as shown.

## Non-inverting Summing Amplifier



So what's the advantage of the non-inverting configuration compared to the inverting summing amplifier configuration. Besides the most obvious fact that the op-amps output voltage  $V_{OUT}$  is "in-phase" with its input, and the output voltage is the weighted sum of all its inputs which themselves are determined by their resistance ratios.

The biggest advantage of the non-inverting summing amplifier is that because there is no virtual earth condition across the input terminals, its input impedance is much higher than that of the standard inverting amplifier configuration.

Also, the input summing part of the circuit is unaffected if the op-amps closed-loop voltage gain is changed. However, there is more maths involved in selecting the weighted gains for each individual

input at the summing junction especially if there are more than two inputs each with a different weighting factor. Nevertheless, if all the inputs have the same resistive values, then the maths involved will be a lot less.

If the closed-loop gain of the non-inverting operational amplifier is made equal the number of summing inputs, then the op-amps output voltage will be exactly equal to the sum of all the input voltages. That is for a two input non-inverting summing amplifier, the op-amps gain is equal to 2, for a three input summing amplifier the op-amps gain is 3, and so on.

This is because the currents which flow in each input resistor is a function of the voltage at all its inputs. If the input resistances made all equal, ( $R_1 = R_2$ ) then the circulating currents cancel out as they can not flow into the high impedance non-inverting input of the op-amp and the output voltage becomes the sum of its inputs.

So for a 2-input non-inverting summing amplifier the currents flowing into the input terminals can be defined as:

$$I_{R1} + I_{R2} = 0 \quad (\text{KCL})$$

$$\frac{V_1 - V^+}{R_1} + \frac{V_2 - V^+}{R_2} = 0$$

$$\therefore \left( \frac{V_1}{R_1} - \frac{V^+}{R_1} \right) + \left( \frac{V_2}{R_2} - \frac{V^+}{R_2} \right) = 0$$

If we make the two input resistances equal in value, then  $R_1 = R_2 = R$ .

$$V^+ = \frac{\frac{V_1}{R} + \frac{V_2}{R}}{\frac{1}{R} + \frac{1}{R}} = \frac{V_1 + V_2}{2}$$

$$\text{Thus } V^+ = \frac{V_1 + V_2}{2}$$

The standard equation for the voltage gain of a non-inverting summing amplifier circuit is given as:

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{V_{OUT}}{V_+} = 1 + \frac{R_A}{R_B}$$

$$\therefore V_{OUT} = \left[ 1 + \frac{R_A}{R_B} \right] V_+$$

$$\text{Thus: } V_{OUT} = \left[ 1 + \frac{R_A}{R_B} \right] \frac{V_1 + V_2}{2}$$

The non-inverting amplifiers closed-loop voltage gain  $A_V$  is given as:  $1 + R_A/R_B$ . If we make this closed-loop voltage gain equal to 2 by making  $R_A = R_B$ , then the output voltage  $V_O$  becomes equal to the sum of all the input voltages as shown.

#### Non-inverting Output Voltage

$$V_{OUT} = \left[ 1 + \frac{R_A}{R_B} \right] \frac{V_1 + V_2}{2}$$

If  $R_A = R_B$

$$V_{OUT} = [1 + 1] \frac{V_1 + V_2}{2} = 2 \frac{V_1 + V_2}{2}$$

$$\therefore V_{OUT} = V_1 + V_2$$

Thus for a 3-input non-inverting summing amplifier configuration, setting the closed-loop voltage gain to 3 will make  $V_{OUT}$  equal to the sum of the three input voltages,  $V_1$ ,  $V_2$  and  $V_3$ .

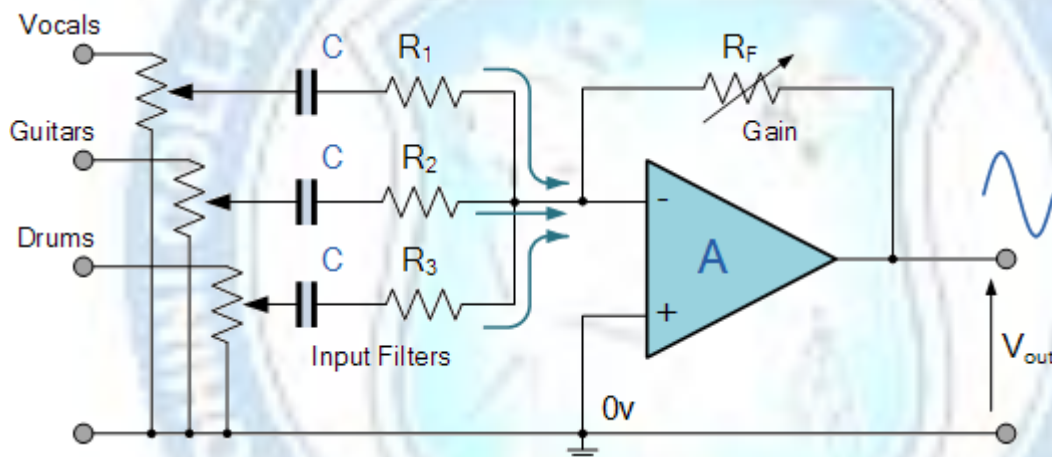
Likewise, for a four input summer, the closed-loop voltage gain would be 4, and 5 for a 5-input summer, and so on. Note also that if the amplifier of the summing circuit is connected as a unity follower with  $R_A$  equal to zero and  $R_B$  equal to infinity, then with no voltage gain the output voltage  $V_{OUT}$  will be exactly equal the average value of all the input voltages. That is  $V_{OUT} = (V_1 + V_2)/2$ .

## Summing Amplifier Applications

So what can we use summing amplifiers for, either inverting or non-inverting. If the input resistances of a summing amplifier are connected to potentiometers the individual input signals can be mixed together by varying amounts.

For example, measuring temperature, you could add a negative offset voltage to make the output voltage or display read “0” at the freezing point or produce an audio mixer for adding or mixing together individual waveforms (sounds) from different source channels (vocals, instruments, etc) before sending them combined to an audio amplifier.

### Simple Audio Mixer Circuit



Another useful and simple application of a **Summing Amplifier** is as a weighted sum digital-to-analogue converter, (DAC). If the input resistors, R<sub>IN</sub> of the summing amplifier double in value for each input, for example, 1kΩ, 2kΩ, 4kΩ, 8kΩ, 16kΩ, etc.

Then a digital logical voltage, either a logic level “0” or a logic level “1” on these inputs will produce an output which is the weighted sum of the digital inputs. Consider the circuit below.