WIKIBOOKS

# Circuit Idea/Parallel Voltage Summer

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## Building a Parallel Voltage Summer

**Building formula:** *Parallel voltage summer = V-to-I converters + current summer + I-to-V converter.*

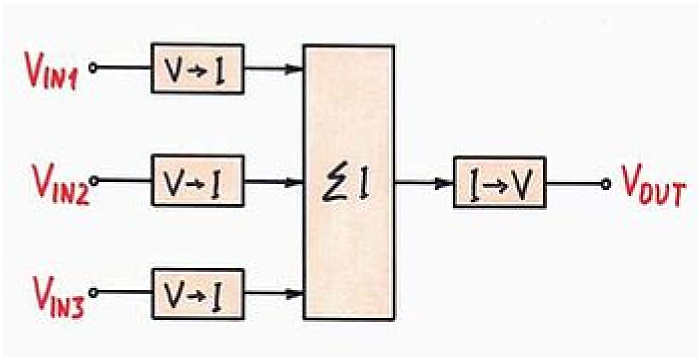


Fig. 1. Parallel voltage summer = V-to-I converters + current summer + I-to-V converter.

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# A problem: *the common ground*

*Kirchhoff's Voltage Law* has already given us an idea how to create the simplest series voltage summer. Unfortunately, it had a lot of disadvantages; maybe, the most crucial of them was the problem of the common ground.

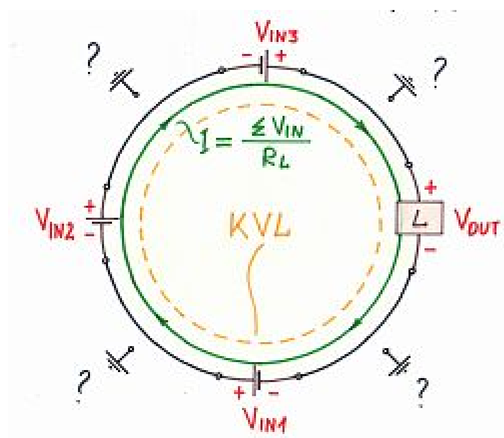


Fig. 2. Where to ground the circuit?

Do you remember? First, we grounded the common point between the input source $V_{IN1}$ and the load; as a result, the sources $V_{IN2}$ and $V_{IN3}$ became flying. Then, we tried to ground the common point between the input sources $V_{IN1}$ and $V_{IN2}$; now, the source $V_{IN3}$ and the load became flying. Finally, we were forced to use only two grounded sources and a differential load.

Only, Kirchhoff has formulated another law - *Kirchhoff's Current Law (KCL)*. Maybe, it can help us to create a perfect voltage summer having no problems with the common ground? Let's try this speculation!

# Deriving the simplest current summer from KCL

First, we can apply directly KCL to create a current summer. For this purpose, we have just to connect in parallel the input current sources $I_i$ (let's for concreteness assume again that we have three sources) to the *current load* $L_I$ (Fig. 3). Let's first assume that it is a perfect *current load* having zero resistance (e.g., just a piece of wire). The output current $I_{OUT}$ flowing through the load is the sum of the input currents: $I_{OUT} = I_{IN1} + I_{IN2} + I_{IN3}$.

We can ask ourselves again, "Only, what is actually the summer here?", "Where is it?" The input current sources and the load are external components; so, the rest (the bare node or the junction point) serves here as a summer!

*The simplest current summer is just a node.*

Wonderful! We have another "ideal" device - the current summer. It is apparent device because there is not actually a device:)!

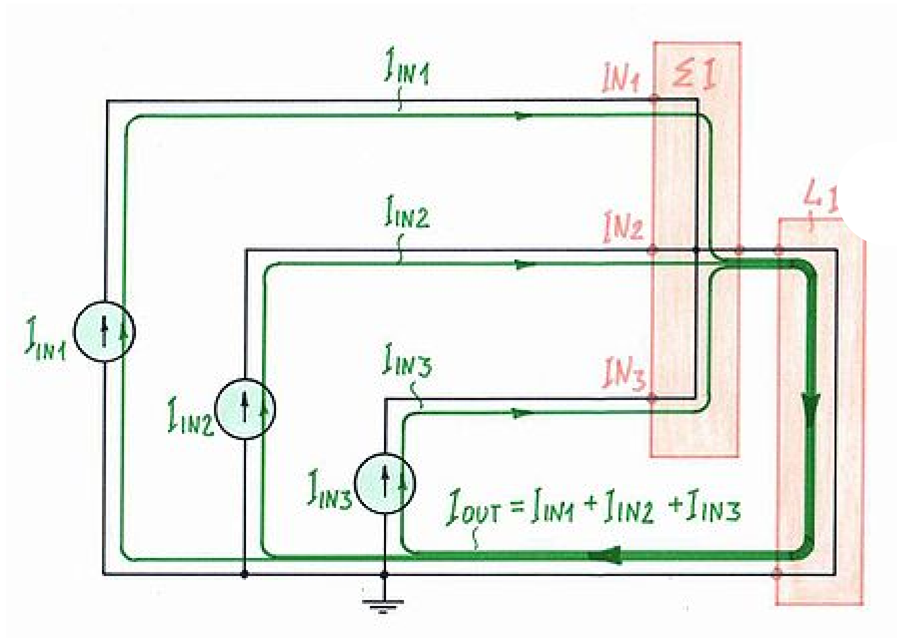


Fig. 3. In order to sum currents, we have just to connect in parallel the input current sources to the load.

# Building a parallel voltage summer

Only, we want to sum input voltages; so, we have to convert them into currents. For this purpose, we connect voltage-to-current converters between the input voltage sources and the inputs of the current summer (Fig. 4). Also, we need a voltage output; so, we have to connect the opposite current-to-voltage converter at the current summer output. In this way, we have assembled a composed voltage summing circuit:

*Parallel voltage summer = V-to-I converters + current summer + I-to-V converter*

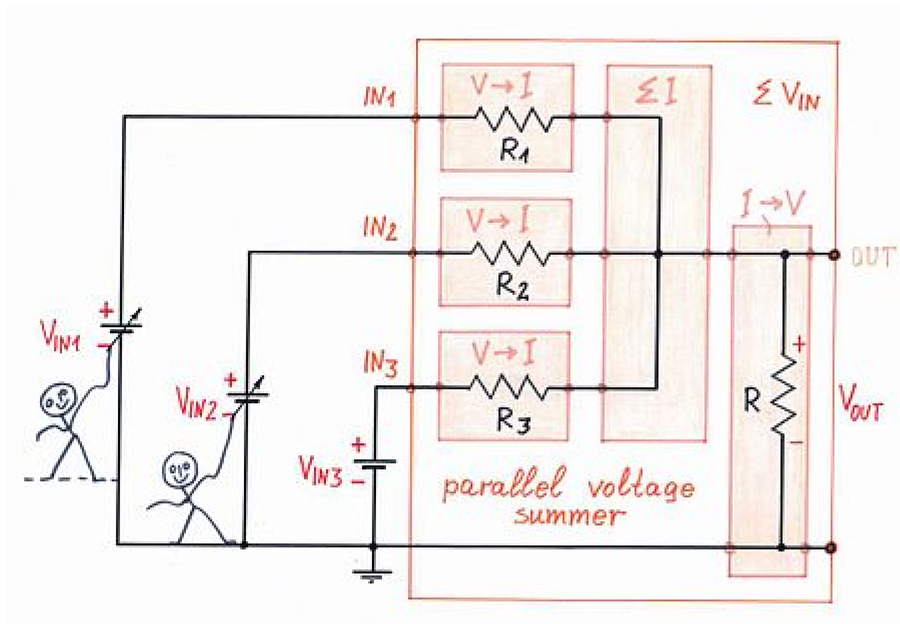


Fig. 4. We can build a parallel voltage summer, if we connect V-toI converters before the inputs and I-to-V converter after the output of a current summer.

Let's compare the two viewpoints: From the classical viewpoint, the parallel voltage summer consists of a few resistors; from our viewpoint, it contains voltage-to-current converters, a current summer and a current-to-voltage converter. The use of applying such a system approach is that we see the function of the resistors in the circuit; we *see the forest for the tree*!

## Exploring the circuit

Let's now see how the circuit operates. Attractive voltage bars will help us to visualize the invisible voltages and voltage drops (Fig. 5); current loops will show us where the currents flow (remember: every current returns where it has begun flowing).

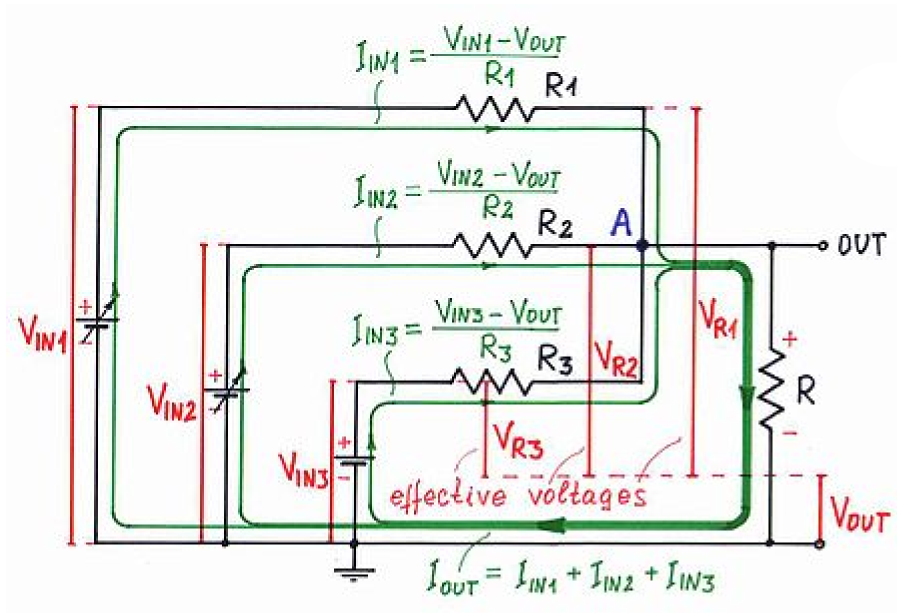


Fig. 5. Visualizing the circuit operation by voltage bars and current loops.

The input voltage sources $V_{IN}$ produce voltages, the resistors $R_{IN}$ convert them into currents, the junction point sums the currents and finally, the resistor R converts back the current sum into an output voltage $V_{OUT}$.

Only, the output voltage introduces an error because it subtracts from the input voltages. Now, the effective voltages $V_{R1}$, $V_{R2}$ and $V_{R3}$ create the currents instead the whole input voltages $V_{IN1}$, $V_{IN2}$ and $V_{IN3}$:

$I_{IN1} = (V_{IN1} - V_{OUT})/R_1 = V_{R1}/R_1$

$I_{IN2} = (V_{IN2} - V_{OUT})/R_2 = V_{R2}/R_2$

$I_{IN3} = (V_{IN3} - V_{OUT})/R_3 = V_{R3}/R_3$

How do we remove the error?

## Do we really need an I-to-V converter?

Maybe, you have already noted the contradictory role of the resistor R.

In order not to disturb the input sources (see above), we want the resistance R to be as small as possible (preferably R = 0). As a result, the input voltage-to-current converters become each other independent; only, the output voltage decreases:( We will use this technique later when we build an active parallel voltage summer.

But why do not we increase the resistance R up to infinity (i.e., just to remove the resistor R)? In this case, the input voltage-to-current converters become each other absolutely dependent but we obtain a maximal output voltage. We can use this solution when the load has an infinite internal resistance (e.g., when we have buffered the passive summer by a non-inverting amplifier).

Only, there is a sound reason to connect the "unnecessary" resistor R - it can add the input coefficients up to 1 (see more explanations). We will use this technique below to build a simple digital-to-analog converter.

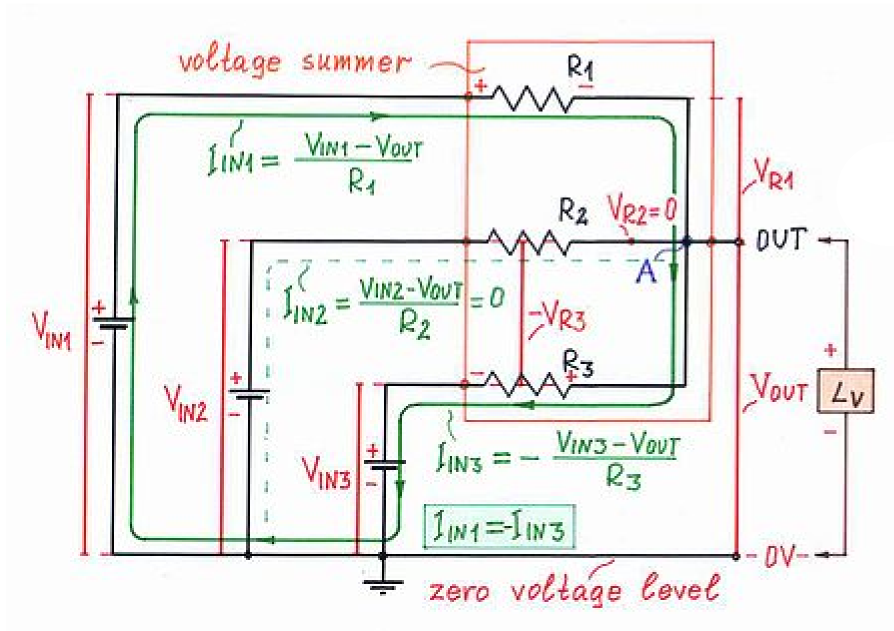


Fig. 6. The circuit continues working fine even, if we remove the I-to-V converter.

# Applications

The parallel voltage summer exists in many analog circuits considered in electronics books; only, authors do not discern and do not pay attention to it. As a result, it is presented rather implicitly than manifestly. In this section, we will do our best to show its presence in various electronic circuits. This famous circuit deserves our attention.

## Op-amp inverting voltage summer

Maybe, the most important application of the passive summer is building an op-amp active summer. Only, what is the idea behind such an op-amp inverting summing circuit (Fig. 7)?

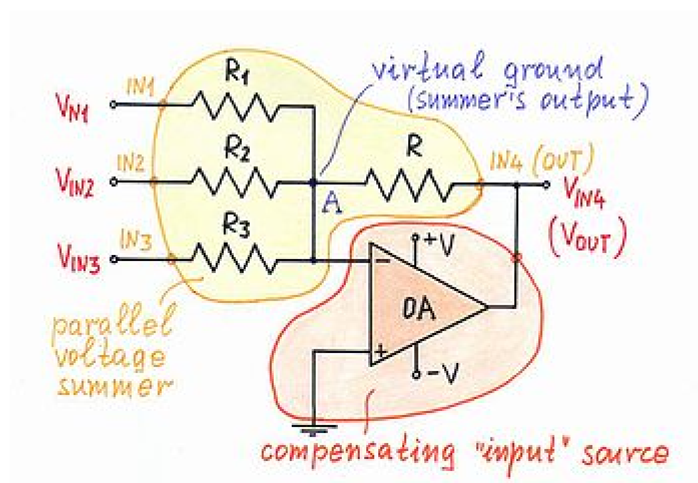


Fig. 7. We can build an op-amp inverting summer by connecting a passive parallel voltage summer and an op-amp.

From the classical viewpoint, an op-amp inverting summer consists of input resistors Ri, a negative feedback resistor R and an op-amp. Only, thinking of the active circuit in this way we can't discern the basic idea behind it; we *do not see the forest for the tree*.

From our fresh viewpoint, an op-amp inverting summer consists of a passive parallel voltage summer and an op-amp:

*Op-amp inverting summer = parallel voltage summer + op-amp*

More precisely speaking, an *n-input* op-amp inverting summer needs an *(n+1)*-input passive parallel voltage summer. For example, in order to build a 3-input op-amp inverting summer (our case) we have to add an additional fourth input $IN_4$. A properly supplied op-amp serves as an additional input voltage source that adjusts its output voltage $V_{OUT}$ (the "input" voltage $V_{IN4}$) so that to zero the passive summer's output voltage $V_A$ (the virtual ground). As a result, the op-amp's output vo' represents the sum of the input voltages $V_{IN}$. Let's repeat again:

*We (i.e., the op-amp) introduce(s) an additional "compensating" input and make its voltage equal to the sum of the rest "true" input voltages. Then, we abandon the "genuine" summer's output voltage $V_A$ (now, it serves only as an indication of an equilibrium) and begin using the compensating voltage $V_{IN4}$ as an output.*

## Digital-to-analog converter

What is a digital-to-analog converter (DAC)? It is just a circuit that materializes an abstract digit (most frequently, converting it into a voltage). A parallel voltage summer having binary-weighted inputs can do this work.

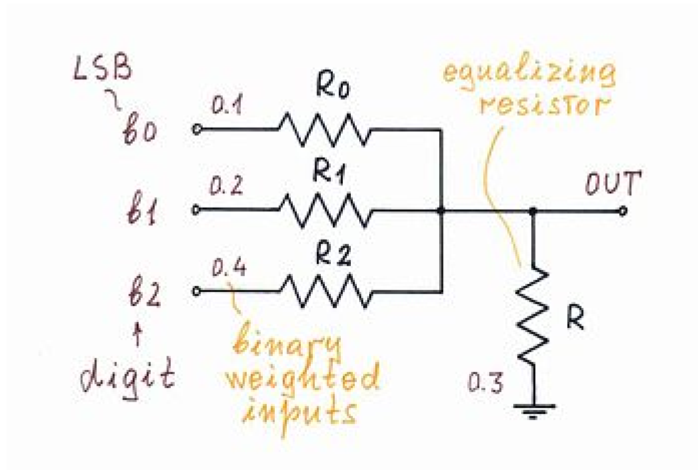


Fig. 8. A parallel voltage summer with binary weighted input coefficients can serve as a DAC.

In this example (Fig. 8), a 3-bit digital device drives the DAC. Here we suppose that the high voltage levels of the three digital outputs are relatively equal; this voltage serves as a reference $V_{REF}$. The output voltage is:

$V_{OUT}$ = 0.1 x b0 x $V_{REF}$ + 0.2 x b1 x $V_{REF}$ + 0.4 x b2 x $V_{REF}$

For example (http://www.daqarta.com/dw_ggdd.htm), you can connect such a simple DAC to the parallel computer port (such as a printer port).

The resistor R is absolutely necessary in this application; it adds the sum of the input coefficients up to 1 (according to Daisy's theorem). You can use the nice Brandy's formula (http://dknollman.122mb.com/k9analysis/Brandy.html) to calculate the resistances.

## Audio mixer

Another popular application of the parallel summing circuit is audio mixing of analog signals from a few voltage sources.

Note again that the parallel summer not just sums the signals; it also attenuates them. In this case, this feature is useful.

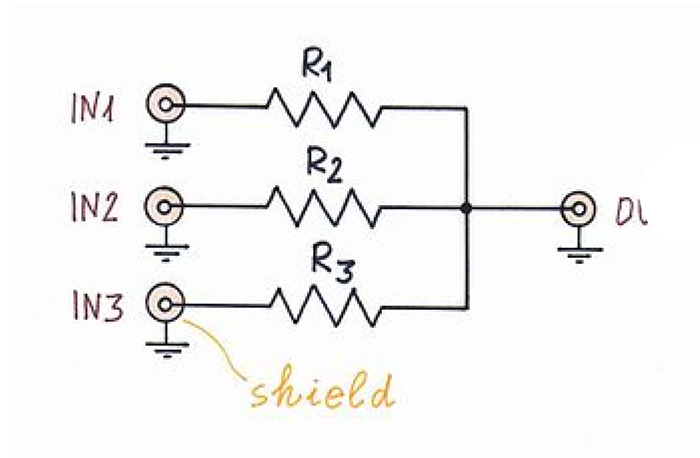


Fig. 9. A parallel voltage summer can mix audio signals.

## Parallel versus series summer

We can do a few remarks about the parallel voltage summing circuit in comparison with the series one.

• The output voltage of the parallel voltage summer is a weighted sum of the input voltages; the output voltage of the series voltage summer is a sum of the whole input voltages.

• The input sources and the load of the parallel voltage summer are grounded; only two devices (sources or a source and a load) of the series configuration can be grounded, the rest remain flying.

## Further reading

Parallel voltage summer (http://www.circuit-fantasia.com/collections/circuit-collection/circuits/old-circuits/v-to-v-sum-old.html) builds the circuit by using the simpler voltage-to-current (http://www.circuit-fantasia.com/collections/circuit-collection/circuits/old-circuits/v-to-i-old.html) and current-to-voltage (http://www.circuit-fantasia.com/collections/circuit-collection/circuits/old-circuits/i-to-v.html) converters (Flash animated; Ruffle plugin (https://chrome.google.com/webstore/detail/ruffle/donbcfbmhbcapadipfkeojnmajbakjdc) is needed).

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