OPERATIONAL AMPLIFIERS

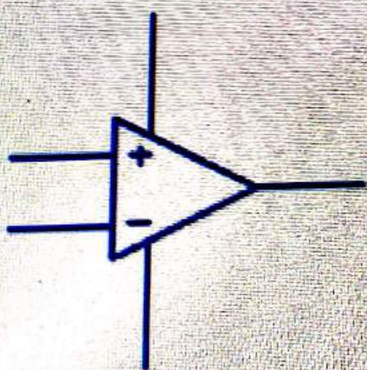
❖ INTRODUCTION

The operational amplifier is an extremely efficient and versatile device. Its applications span the broad electronic industry filling requirements for signal conditioning, special transfer functions, analog instrumentation, analog computation, and special systems design. The analog assets of simplicity and precision characterize circuits utilizing operational amplifiers.

❖ OP-AMP BASICS

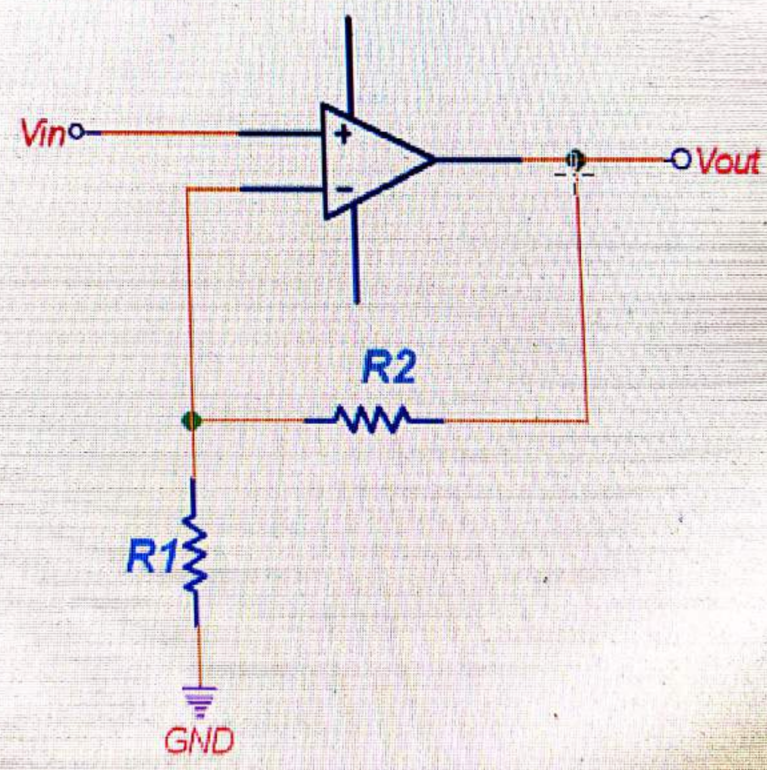
Operational amplifiers are convenient building blocks that can be used to build amplifiers, filters, and even an analog computer. Op-amps are integrated circuits composed of many transistors & resistors such that the resulting circuit follows a certain set of rules. The most common type of op-amp is the voltage feedback type and that's what we'll use.

The schematic representation of an op-amp is shown to the left. There are two input pins (non-inverting and inverting), an output pin, and two power pins. The ideal op-amp has infinite gain. It amplifies the voltage difference between the two inputs and that voltage appears at the output. Without feedback this op-amp would act like a comparator (i.e. when the non-inverting input is at a higher voltage than the inverting input the output will be high, when the inputs are reversed the output will be low).



❖ NON-INVERTING AMPLIFIER:

No current flows into the input, Rin = ∞ The output adjusts to bring Vin- to the same voltage as Vin+. Therefore Vin- = Vin and since no current flows into Vin- the same current must flow through R1 & R2. Vout is therefore VR1 + VR2 = Vin- + IR2 = Vin- + (Vin/R1)R2.



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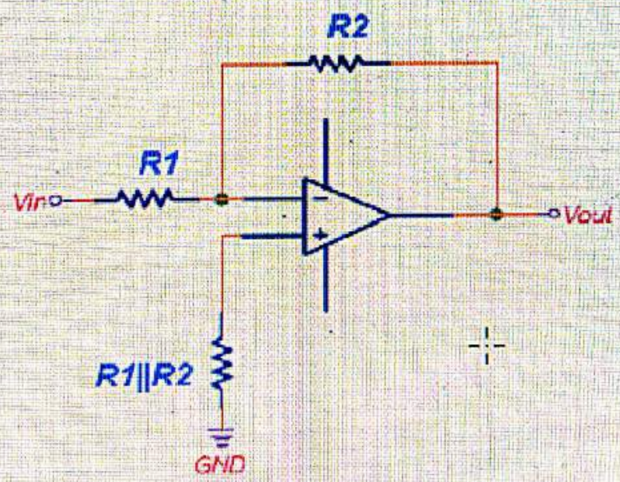
❖ INVERTING AMPLIFIER

Because no current flows into the input pins there can't be any voltage drop across the R1 || R2. Vin+ is therefore at 0V(this is called a virtual ground). The output will adjustsuch that Vin- is at zero volts. This makes **Rin = R1** (not ∞). The current through R1 & R2 have to be the same since no current goes into the input pins.
Therefore I = Vin/R1. Vout = Vin+ - IR2 = 0 - (Vin/R1)R2. Therefore **Vout = -Vin(R2/R1)**

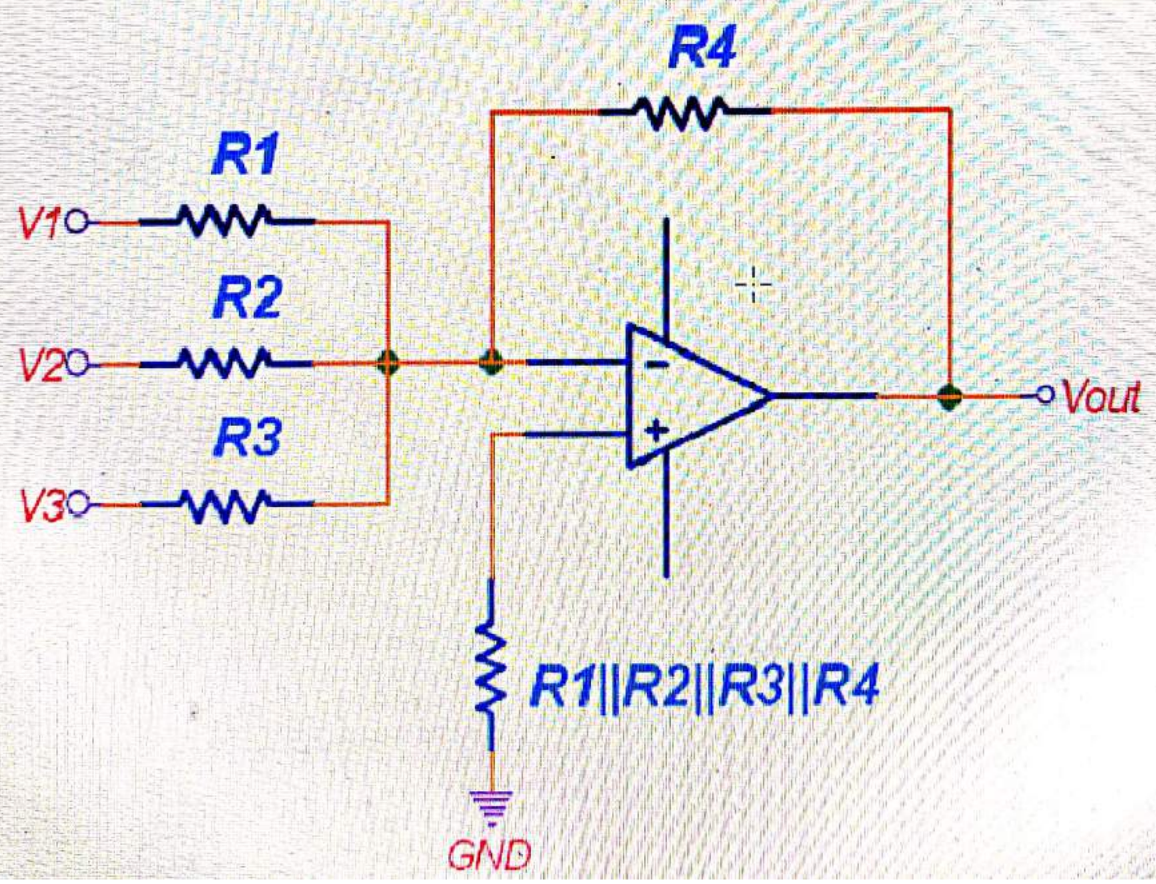


❖ SUMMING AMPLIFIER:

Since Vin- is a virtual ground adding V2 and R2 (and V3 & R3) doesn't change the current flowing through R1 from V1. Each input contributes to the output using the following equation:

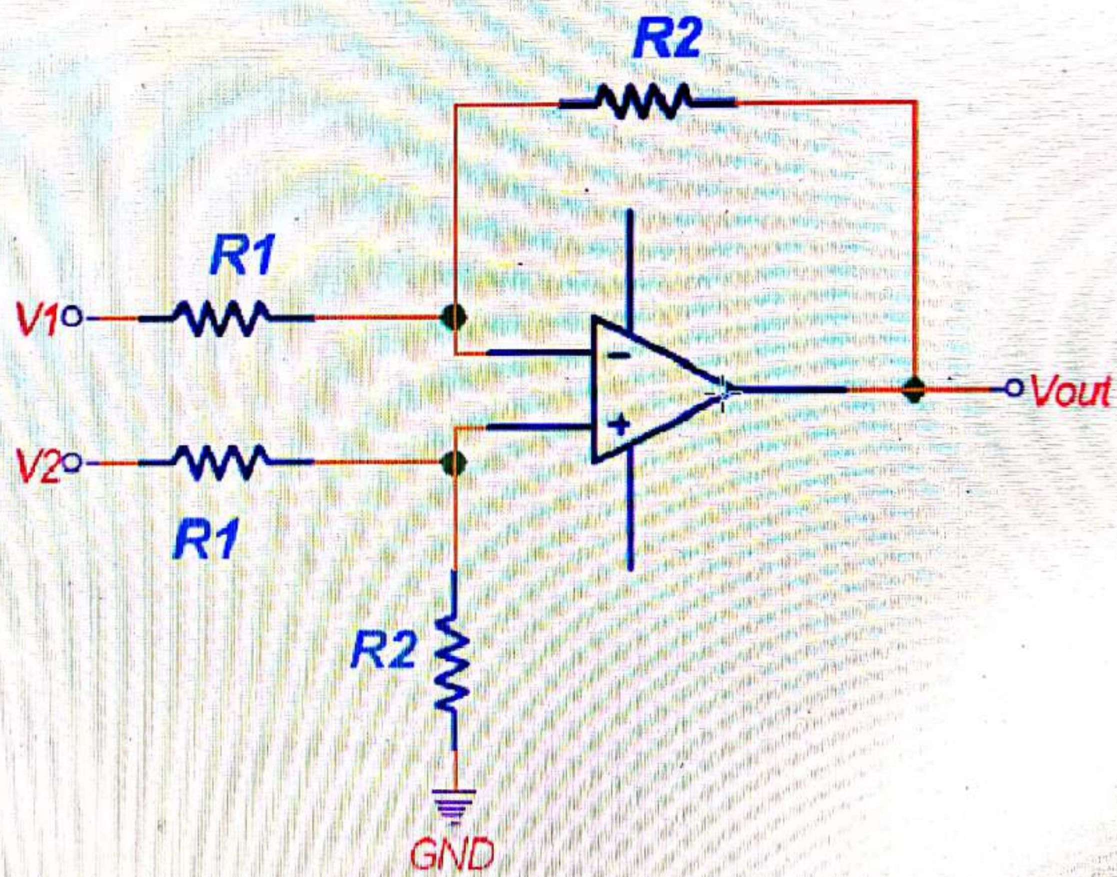
Vout = -V1(R4/R1) - V2(R4/R2) - V3(R4/R3).

The input impedance for the V1 input is still R1, similarly V2's input impedance is R2 and V3's is R3. Most of the time the parallel combination of R1-R4 isn't used and Vin+ is grounded.



❖ DIFFERENCE AMPLIFIER:

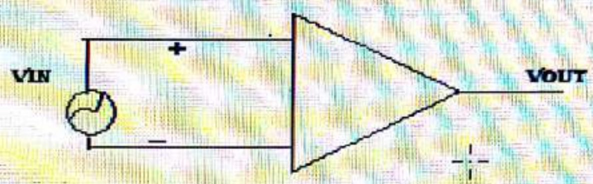
You can work out the gain as before using the two rules (no current flows into the inputs, and the output will adjust to bring Vin- to Vin+). The result is **Vout = 2(V2-V1)*(R2/R1).** Also, **Rin(-) = R1, Rin(+) = R1 + R2.**



❖ COMMON-MODE OP- AMP

These type of op-amp have common mode voltage to both terminals.

It means without connecting the same voltage at both the terminal we may connect one voltage or either inverting or non-inverting terminal and other is connected with short to that voltage.



❖ COMMON MODE REJECTION RATIO

Common mode rejection ratio which is defined as the ratio of differential gain to common mode

$$CMRR = A_d / A_{cm}$$

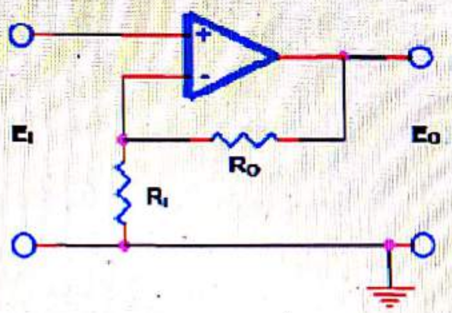
$$A_d = V_0 / V_d \quad , \quad A_{cm} = V_0 / V_{cm}$$

As the gain is generally high so CMRR is used to express as a logarithmic gain function

$$CMRRR = 20\log A_d/A_{cm}$$

❖ OPERATIONAL - AMPLIFIER WITH FEEDBACK

Non-Inverting Amplifier



$$E_O = \left(1 + \frac{R_O}{R_I}\right) \cdot E_I$$

The same voltage must appear at the inverting and non-inverting inputs, so that:

$$(E-) = (E+) = E_I$$

From the voltage division formula:

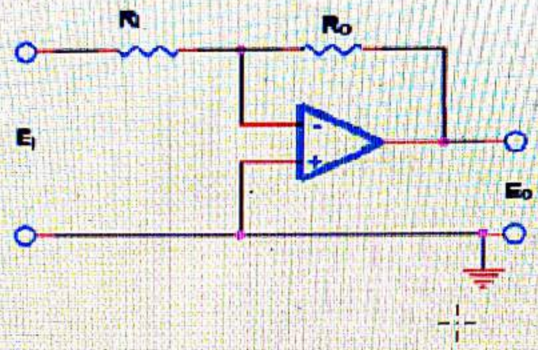
$$E_I = \frac{R_I}{R_I + R_O} \cdot E_O$$

$$\frac{E_O}{E_I} = \frac{R_I + R_O}{R_I} = 1 + \frac{R_O}{R_I}$$

The input impedance of the non-inverting amplifier circuit is infinite since no current flows into the inverting input. Output impedance is zero since output voltage is ideally independent of output current. Closed loop gain is $1 + \frac{R_O}{R_I}$ hence can be any desired value above unity.

Such circuits are widely used in control and instrumentation where non-inverting gain is required.

INVERTING AMPLIFIER



$$\frac{E_o}{E_I} = \frac{-R_o}{R_I}$$

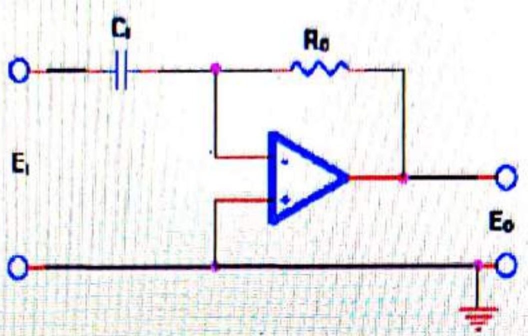
Figure 17. Inverting Amplifier

The inverting amplifier appears in figure 17. This circuit and its many variations form the bulk of commonly used operational amplifier circuitry. Single ended input and output versions were first used, and they became the basis of analog computation. Today's modern differential input amplifier is used as an inverting amplifier by grounding the non-inverting input and applying the input signal to the inverting input terminal.

Since the amplifier draws no input current and the input voltage approaches zero when the feedback loop is closed (the two summing point restraints), we may write:

$$\frac{E_I}{R_I} = \frac{E_O}{R_O} = 0$$

Differentiator



$$E_o = -R_o C_1 \frac{dE_1}{dt}$$

Figure 22. Differentiator Circuit

Using a capacitor as the input element to the inverting amplifier, figure 22, yields a differentiator circuit. Consideration of the device in figure 23 will give a feeling for the differentiator circuit.

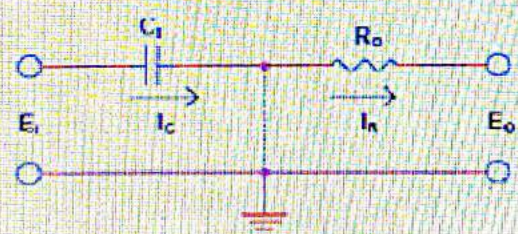


Figure 23. An Intuitive Picture of the Differentiator

Since the inverting input is at ground potential:

$$I_C = C_I \frac{dE_I}{dt}, \text{ and } I_C - I_R = 0$$

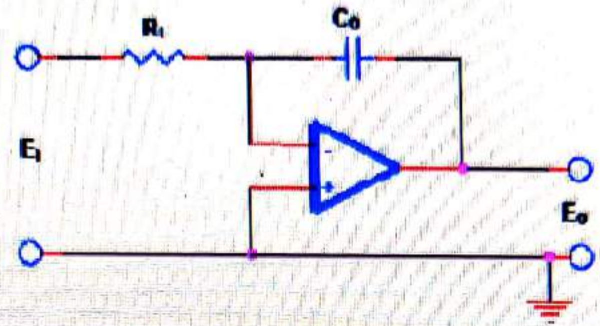
so that:

$$C_I \frac{dE_I}{dt} + \frac{E_O}{R_O} = 0$$

$$E_O = -R_O C_I \frac{dE_I}{dt}$$

It should be mentioned that of all the circuits presented in this section, the differentiator is the one that will operate least successfully with real components. The capacitive input makes it particularly susceptible to random noise and special techniques will be discussed later for remedying this effect.

Integrator



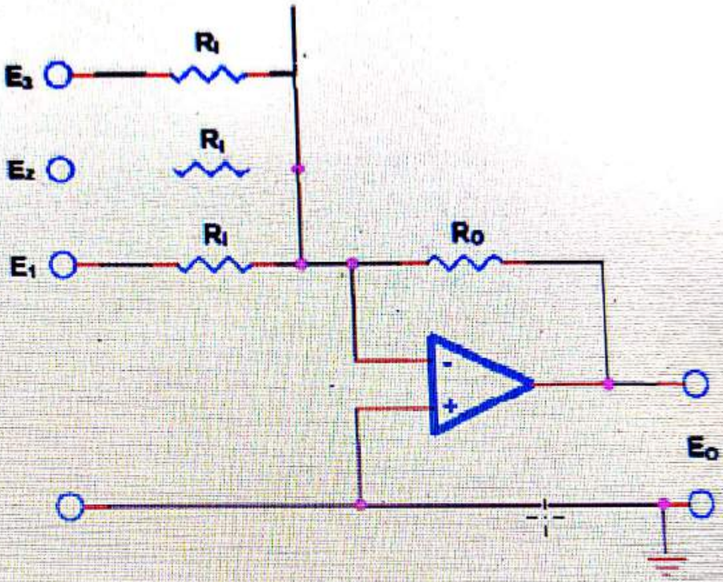
$$E_O = \frac{-1}{R_I C_O} E_I dt$$

Figure 21. Integrator Circuit

If a capacitor is used as the feedback element in the inverting amplifier, shown in figure 21, the result is an integrator. An intuitive grasp of the integrator action may be obtained from the statement under the section, "Current Output," that current through the feedback loop charges the capacitor and is stored there as a voltage from the output to ground. This is a voltage input current integrator.

Voltage Adder

In a great many practical applications the input to the inverting amplifier is more than one voltage. The simplest form of multiple inputs is shown in figure 24.

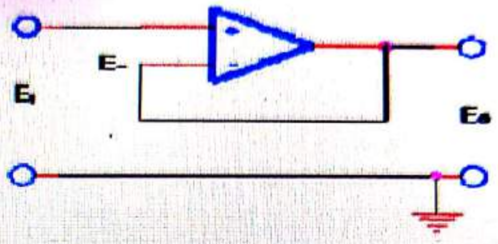


$$E_O = \frac{-R_O}{R_I}(E_1 + E_2 + E_3 + \ldots)$$

Figure 24. Voltage Adding Circuit

Current in the feedback loop is the algebraic sum of the current due to each input. Each source E_1, E_2, etc., contributes to the total current, and no interaction occurs between them. All inputs "see" R_I as the input impedance, while gain is $\frac{-R_O}{R_I}$. Direct voltage addition may be obtained with $R_O = R_I$.

THE VOLTAGE FOLLOWER



Let the voltage at the inverting input with respect to the non-inverting input be E-.

By Kirchoff's voltage law:

$$(E-)+E_I=E_O$$

But by definition:

$$E_O=-A(E-)$$

where A is the gain of the operational amplifier

Then:

$$(E-)=\frac{-E_O}{A}$$

And substituting:

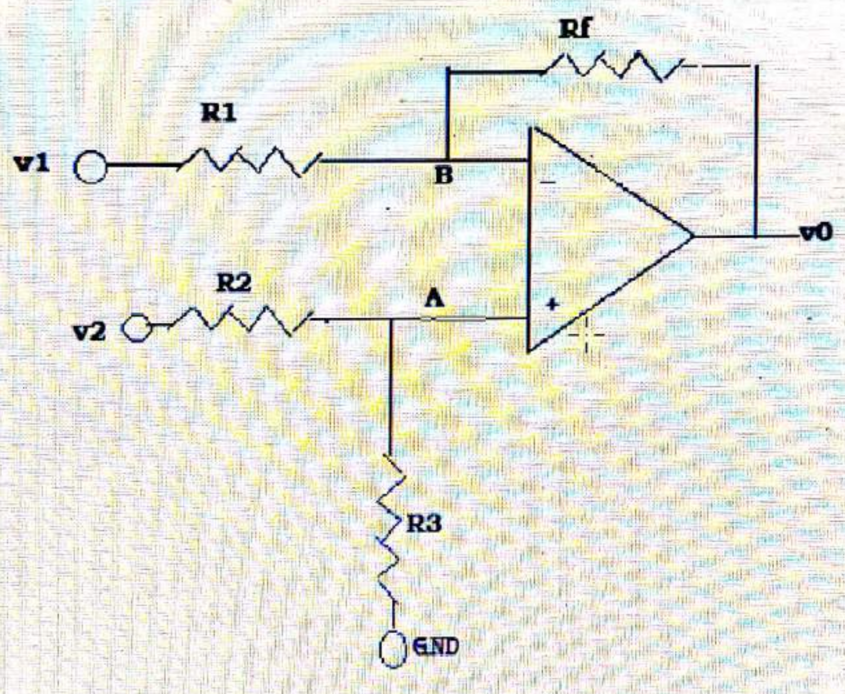
$$E_I-\frac{E_O}{A}=E_O$$

Letting A go to infinity, $\frac{E_O}{A}$ approaches zero, and:

$$E_O=E_I$$

❖ VOLTAGE SUBSTRACTOR

➢ Generally Subtraction of signals are being perfomed by substracting one signal from another signal. These types of subtractor are always used in analog signals.



Voltage across terminal A can be found by using voltage division rule and we know that voltage across A is equals to the B so VA = VB

VA= V2 .R2/ R2+R3 = VB

Applying nodal analysis in terminal B the equation becomes

(VB – V 1)/R1 + (VB-V0) / RF = 0

VB/R1 + (VB/RF – V1/R1) = V0/RF

VB (1/R1 + 1/RF) –V1/R1 = V0/RF

But we know that VB= V2 .R2/ R2+R3

(V2 .R2/ R2+R3) [(RF+R1)/R1 .RF] – V1 /R1 = V0/RF

(V2 .R2/ R2+R3) [(RF+ R1)/R1] – V1. RF/R1 = V0

V0= (V2 .R2/ R2+R3) [1+ RF/R1] – (V1. RF)/ R1

If we put RF= R1 =R2 =R3 = 1 KΩ

The output voltage V0 becomes

V0 = V2 – V1

SLEW RATE

It is the ratio of change in output voltage to change in time

$S.R = \Delta V0 / \Delta T$ (V/µs)