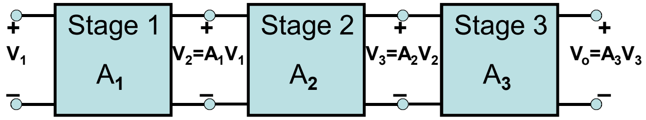
# 5.8 Cascaded op amp circuits

-------- The figure and property



## Cascaded op amp circuits

**A cascade connection** is a head-to-tail arrangement of two or more op amp circuits such that the output of one is the input of the next.




A three-stage cascaded connection

Since the output of one stage is the input to the next stage, the overall gain of the cascade connection is the product of the gains of the individual op amp circuits,or

$$A=A_1A_2A_3$$

# 5.11 Summary and Review



## 5.11 Summary

1. The op amp is a **high-gain** amplifier that has **high input resistance** and **low output resistance**.

2. Table 5.3 summarizes the op amp circuits considered in this chapter. The expression for the gain of each amplifier circuit holds whether the inputs are dc, ac, or time-varying in general.

3. An ideal op amp has an **infinite input resistance**, **a zero output resistance**, and **an infinite gain**.

4. For an ideal op amp, the current into each of its two input terminals is zero, and the voltage across its input terminals is negligibly small.

5. In an inverting amplifier, the output voltage is a **negative multiple** of the input.

6. In a noninverting amplifier, the output is a **positive multiple** of the input.



7. In a voltage follower, the output follows the input.

8. In a summing amplifier, the output is the **weighted sum** of the inputs.

9. In a difference amplifier, the output is **proportional to** the difference of the two inputs.

10. Op amp circuits may be **cascaded** without changing their input-output relationships.



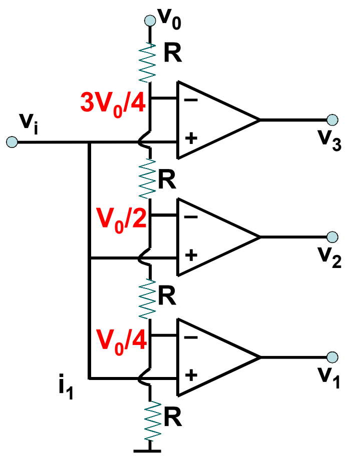
11. *Pspice* can be used to analyze an op amp circuit.

12. **Typical applications** of the op amp considered in this chapter include the **digital-to-analog converter** and **the instrumentation amplifier**.



**Example**: The analog-to-digital converter, let $V_{CC}$=5V, $V_0$=4V. When 0<t<4s, $V_i$=t (V). Find the output $V_3$, $V_2$, $V_1$.

**Solution**:



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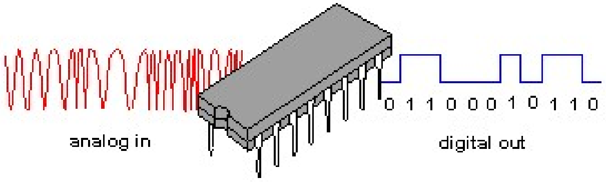


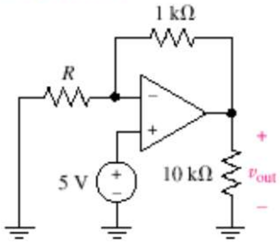



| Time | Input voltage | Output voltage | | |
|---|---|---|---|---|
| 0<t<1 | 0<Vi<1 | $V_3$=-5 | $V_2$=-5 | $V_1$=-5 |
| 1<t<2 | 1<Vi<2 | $V_3$=-5 | $V_2$=-5 | $V_1$=+5 |
| 2<t<3 | 2<Vi<3 | $V_3$=-5 | $V_2$=+5 | $V_1$=+5 |
| 3<t<4 | 3<Vi<4 | $V_3$=+5 | $V_2$=+5 | $V_1$=+5 |



**Example:** In the circuit of Fig. 6.24, what value of $R$ is required so that 150 mW is delivered to the 10-kΩ resistor?

**Figure 6.24**






**Solution:** In order to deliver 150 mW to the 10-kΩ resistor, we need $v_{out} = \sqrt{(0.15)(10\times10^3)} = 38.73$ V.

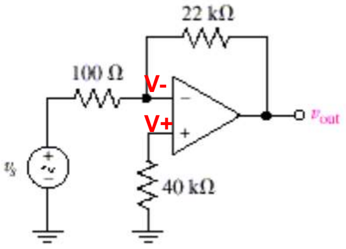
Writing a nodal equation at the inverting input, we find

$$0 = \frac{5}{R} + \frac{5 - v_{out}}{1000}$$

Using $v_{out}$ = 38.73, we find that R = 148.2 Ω.

**Example:** For the circuit of Fig. 6.25, derive an expression for $\mathbf{v_{out}}$ in terms of $\mathbf{v_s}$.

Figure 6.25






**Solution:** We begin by labeling the nodal voltages *v-* and *v+* at the inverting and non-inverting input terminals, respectively. Since no current can flow into the non-inverting input, no current flows through the 40-kΩ resistor; hence, *v+* = 0. Therefore, we know that *v-* = 0 as well. Writing a single nodal equation at the non-inverting input then leads to

$$0 = \frac{(v_- - v_S)}{100} + \frac{(v_- - v_{out})}{22000}$$

or

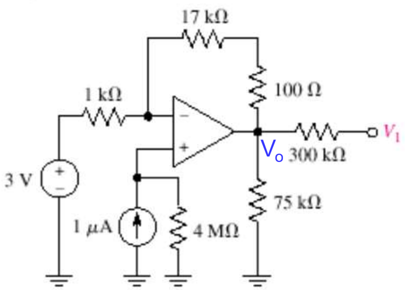
$$0 = \frac{-v_S}{100} + \frac{-v_{out}}{22000}$$

$$v_{out} = -220\, v_S$$



**Example:** For the circuit of Fig. 6.26, calculate the voltage $V_1$.

Figure 6.26




**Solution:** We first label the nodal voltage at the output pin $V_o$. Then, writing a single nodal equation at the inverting input terminal of the op amp,



$$0 = \frac{4-3}{1000} + \frac{4-V_o}{17000}$$

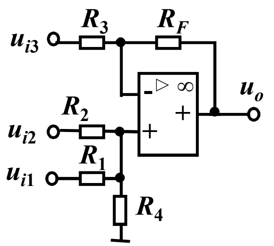
Solving, we find that $V_o = 21$ V. Since no current can flow through the 300-kΩ resistor, $V_1 = 21$V as well.

例：设计一个加减运算电路，$R_F$=240kΩ，使

$$u_o=10u_{i1}+8u_{i2}-20u_{i3}$$

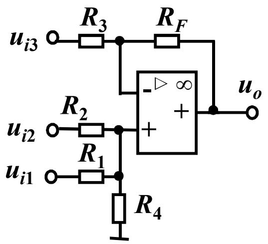
解：(1) 画电路。

系数为负的信号从反相端输入，系数为正的信号从同相端输入。






(2) 求各电阻值。




$$\begin{cases} R_1 // R_2 // R_4 = R_3 // R_F \\ u_o = R_F\left(\dfrac{u_{i1}}{R_1}+\dfrac{u_{i2}}{R_2}-\dfrac{u_{i3}}{R_3}\right) \\ R_F = 240\text{k}\Omega \end{cases}$$

$$u_o=10u_{i1}+8u_{i2}-20u_{i3}$$

$R_1 = 24\text{k}\Omega$

$R_2 = 30\text{k}\Omega$

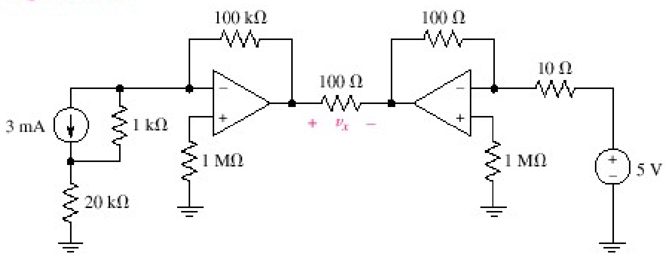
$R_3 = 12\text{k}\Omega$

$R_4 = 80\text{k}\Omega$



**Example**: Compute $v_x$ for the multiple op amp circuit of Fig. 6.36.

**Figure 6.36**






**Solution**: The 3 mA source, 1 kΩ resistor and 20 kΩ resistor may be replaced with a –3 V source ("+" reference up) in series with a 21 kΩ resistor. No current flows through either 1 MΩ resistor, so that the voltage at each of the four input terminals is identically zero. Considering each op amp circuit separately,

$$v_{out}\Big|_{LEFTOPAMP} = -(-3)\frac{100}{21} = 14.29\text{ V}$$

$$v_{out}\Big|_{\text{RIGHT OPAMP}} = -(5)\frac{100}{10} = -50\text{ V}$$

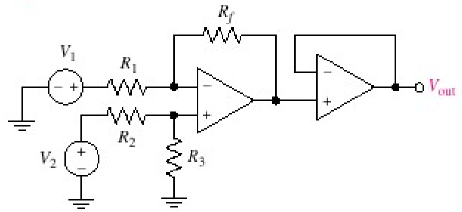
$$v_{out}\Big|_{\text{LEFTOPAMP}} - v_{out}\Big|_{\text{RIGHT OPAMP}}$$

$$= 14.29 + 50 = 64.29\text{ V.}$$

Electric Circuits

**Example:** Derive an expression for $V_{out}$ in terms of $V_1$ and $V_2$ for the circuit of Fig. 6.39.

**Figure 6.39**




Electric Circuits

**Solution:** We have a difference amplifier as the first stage, and a simple voltage follower as the second stage. We therefore need only to find the output voltage of the first stage: $v_{out}$ will track this voltage. Using voltage division, then, we find that the voltage at the non-inverting input pin of the first op amp is

$$V_2\left(\frac{R_3}{R_2+R_3}\right)$$

and this is the voltage at the inverting input terminal also. Thus, we may write a single nodal equation at the inverting input of the first op amp:

Electric Circuits

$$\frac{1}{R_1}\left[V_2\left(\frac{R_3}{R_2+R_3}\right)-V_1\right] = -\frac{1}{R_f}\left[V_2\left(\frac{R_3}{R_2+R_3}\right)-V_{out}\Big|_{Stage\,1}\right]$$

which may be solved to obtain:

$$V_{out} = V_{out}\Big|_{Stage1} = \left(\frac{R_f}{R_1}+1\right)\frac{R_3}{R_2+R_3}V_2 - \frac{R_f}{R_1}V_1$$