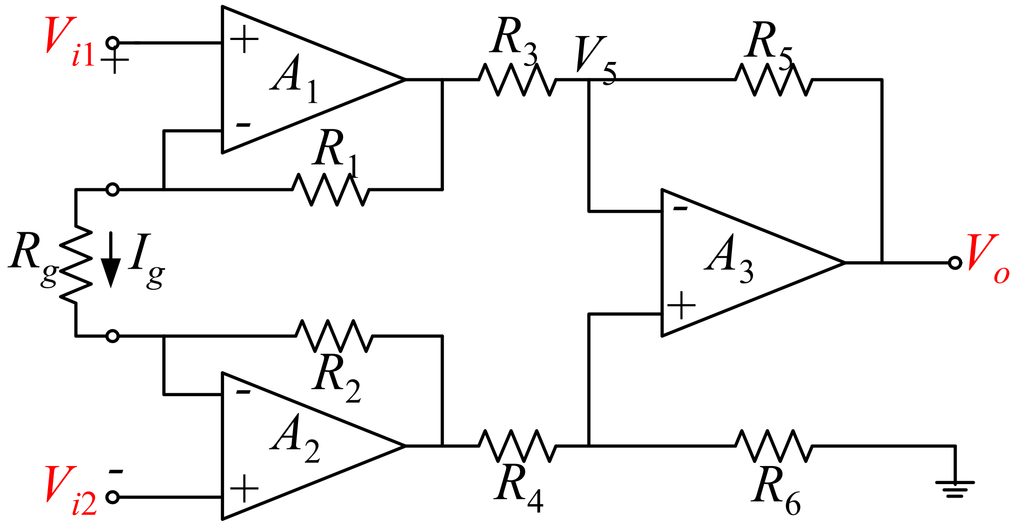
第七章 微弱信号处理电路

7.1 测量放大器

测量放大器

- Instrumentation amplifier
  - 仪表放大器、仪用放大器
- 可以用于放大微弱差值信号的高精度放大器
- 具有差分输入、单端输出、高输入阻抗和高共模抑制比等特点
- 在测量控制等领域具有广泛的用途

测量放大器电路



三运放测量放大器

- 外接电阻R_g，用于调整放大器的放大系数
- 运放A_3将双端输入变为对地的单端输出
- $R_1 = R_2$，$R_3 = R_4$，$R_5 = R_6$

差模增益

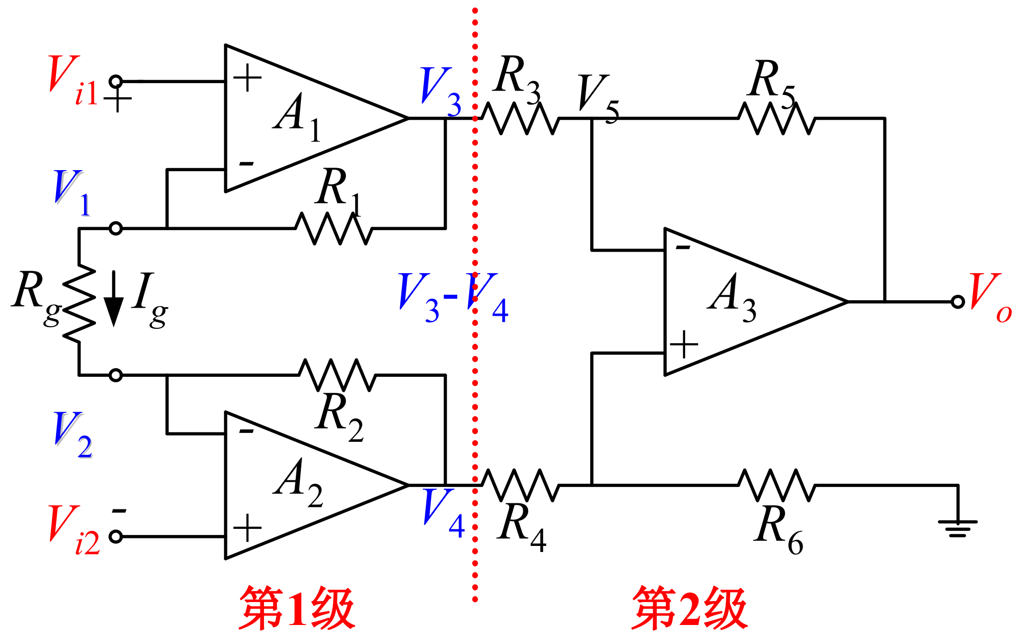
R_g两端电压平均值就是输入共模分量 $\dfrac{V_1+V_2}{2}=\dfrac{V_{i1}+V_{i2}}{2}$

- 假设理想运放

$$V_1=V_{i1},\quad V_2=V_{i2}$$

$$I_g=\frac{V_1-V_2}{R_g}=\frac{V_{i1}-V_{i2}}{R_g}$$

$$V_3-V_4=\left(R_g+R_1+R_2\right)I_g$$



$$\boxed{V_3-V_4=\left(1+\frac{2R_1}{R_g}\right)\left(V_{i1}-V_{i2}\right)}$$

第1级电路实现了对输入差分信号的放大

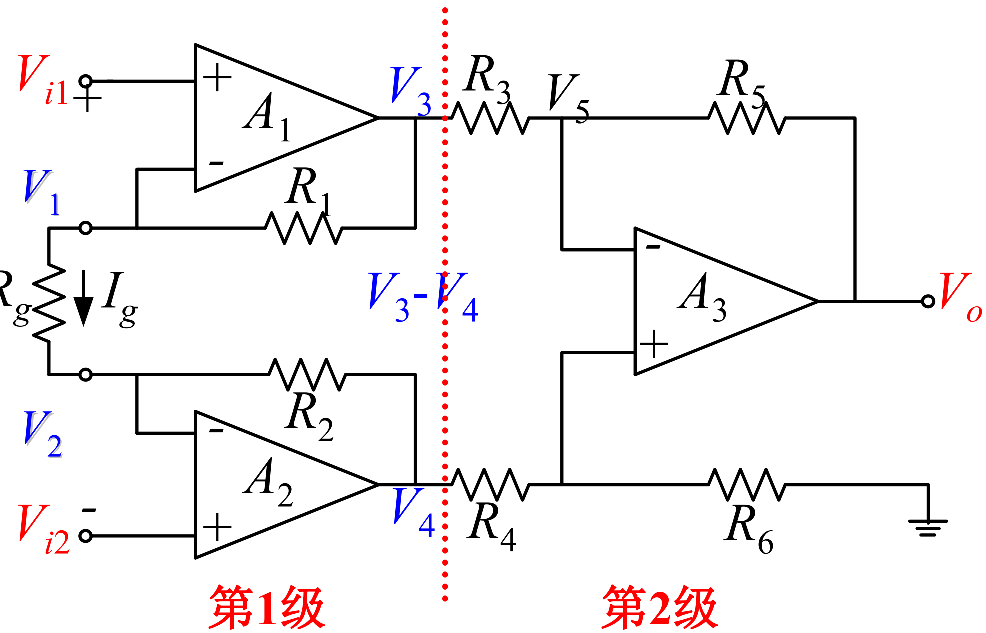
差模增益

- 第1级电路

$$V_3 - V_4 = \left(1 + \frac{2R_1}{R_g}\right)(V_{i1} - V_{i2})$$

- 第2级电路（减法放大器）

$$V_o = -\frac{R_5}{R_3}(V_3 - V_4)$$



$$V_o = -\frac{R_5}{R_3}\left(1 + \frac{2R_1}{R_g}\right)(V_{i1} - V_{i2})$$

$$\boxed{A_{vd} = \frac{V_o}{V_{i1} - V_{i2}} = -\frac{R_5}{R_3}\left(1 + \frac{2R_1}{R_g}\right)}$$

$R_1 = R_2 = 5k\Omega, R_g = 100k\Omega$

$R_3 = R_4 = 10k\Omega, R_5 = R_6 = 20k\Omega$

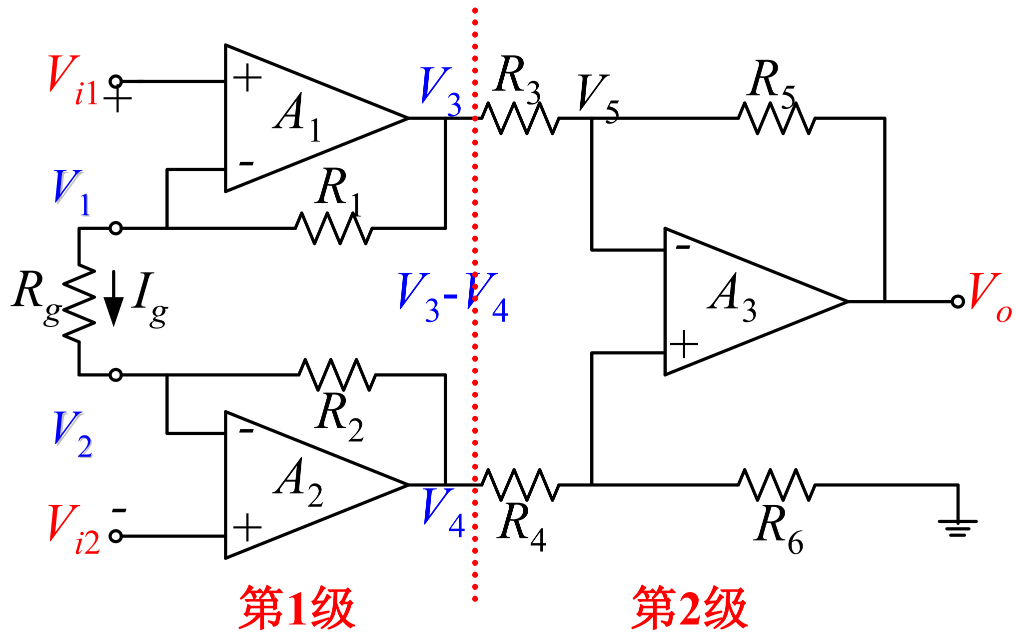
$A_{vd} = -2.2$ **反相放大**

共模增益

$$V_{i1} = V_{i2}, \quad V_{i1} - V_{i2} = 0$$

$$V_1 = V_{i1}, \quad V_2 = V_{i2}$$

$$I_g = \frac{V_1 - V_2}{R_g} = \frac{V_{i1} - V_{i2}}{R_g} = 0$$



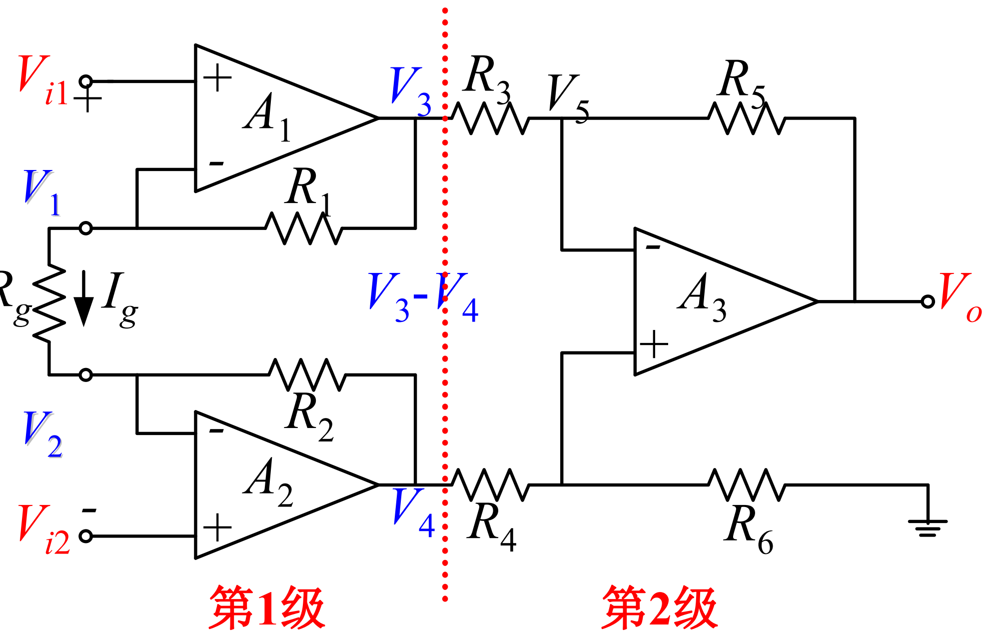
$$\boxed{(V_3 = V_{i1}) = (V_4 = V_{i2})}$$

第1级电路把输入共模分量“传递”到了输出端

共模增益

- 第2级电路（减法放大器）

$$V_o = \frac{R_6\left(R_3 + R_5\right)}{R_3\left(R_4 + R_6\right)} V_4 - \frac{R_5}{R_3} V_3$$



$$V_o = \frac{R_6 R_3 - R_4 R_5}{R_3\left(R_4 + R_6\right)} V_{i1}$$

$$\boxed{A_{vc} = \frac{V_o}{V_{i1}} = \frac{R_6 R_3 - R_4 R_5}{R_3\left(R_4 + R_6\right)}}$$

假设电路对称 $R_3 = R_4, R_5 = R_6, A_{vc} = 0$

共模抑制比

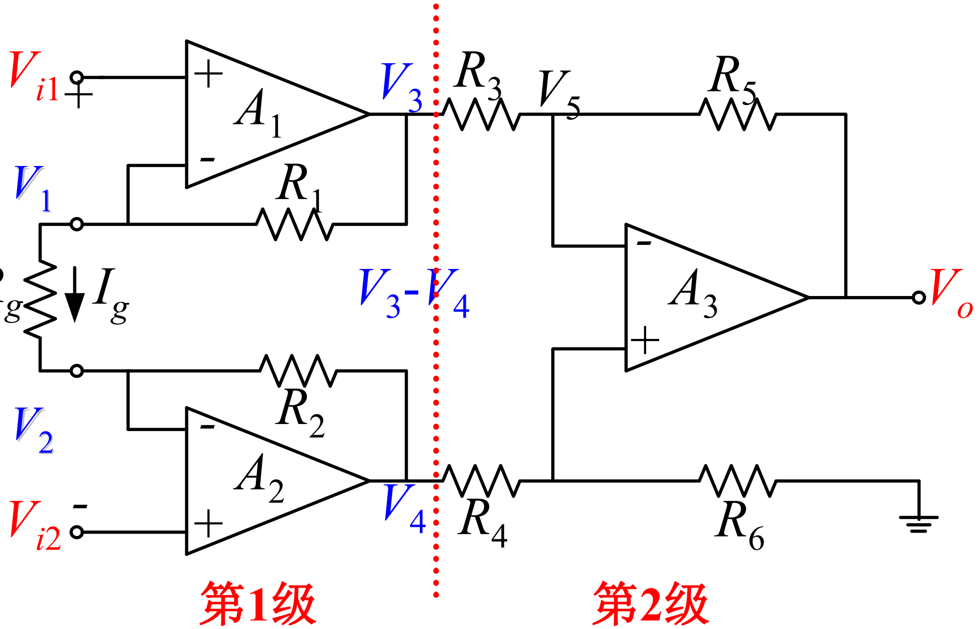
- 假设理想运放且电路对称

$$CMRR = 20\lg\left|\frac{A_{vd}}{A_{vc}}\right| = \infty$$

- 假设理想运放但电路不对称

$R_4 = 10.01k\Omega, R_5 = 20.02k\Omega$

$$A_{vc} = \left[\frac{20\times10-10.01\times20.02}{10\times(10.01+20)}\right] = -0.00133$$



$$CMRR = 20\lg\left|\frac{A_{vd}}{A_{vc}}\right| = 20\lg\left|\frac{2.2}{0.00133}\right| = 64.37dB$$

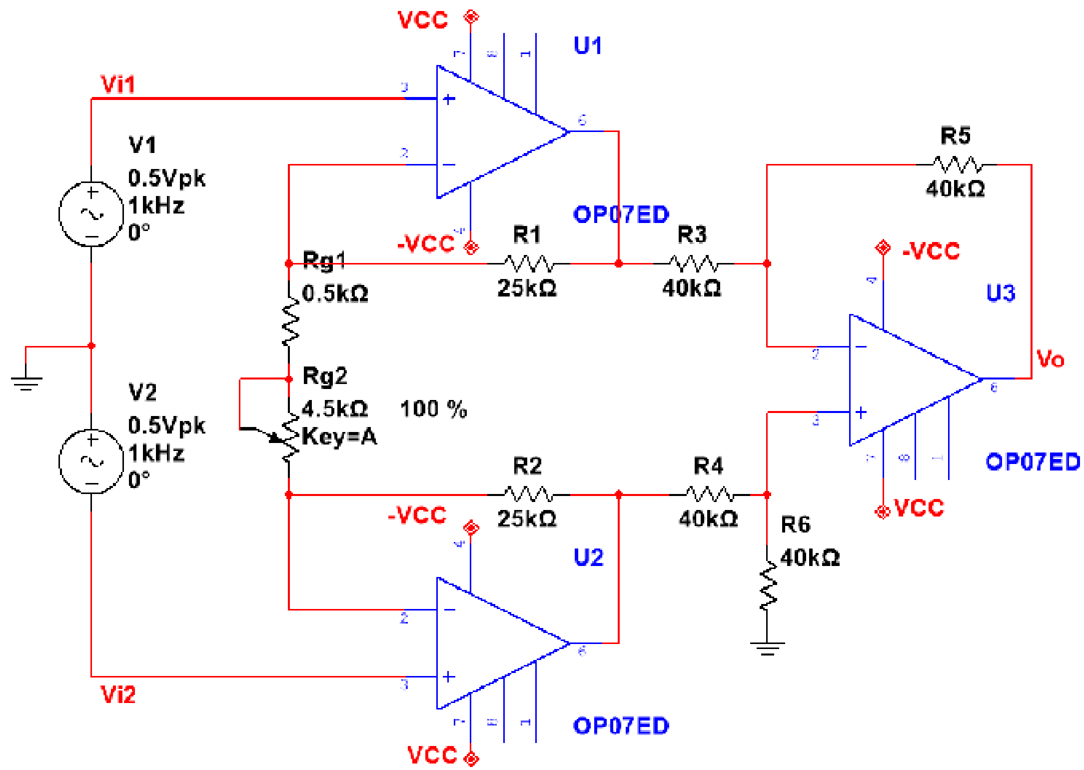
测量放大器仿真

- 采用OP07运放
  - ±15V供电
  - 输入失调电压小
  - 共模抑制比高

- 增益调节电阻R_g
  - $0.5\text{k}\Omega \sim 5\text{k}\Omega$
  - 差模增益-11~-101

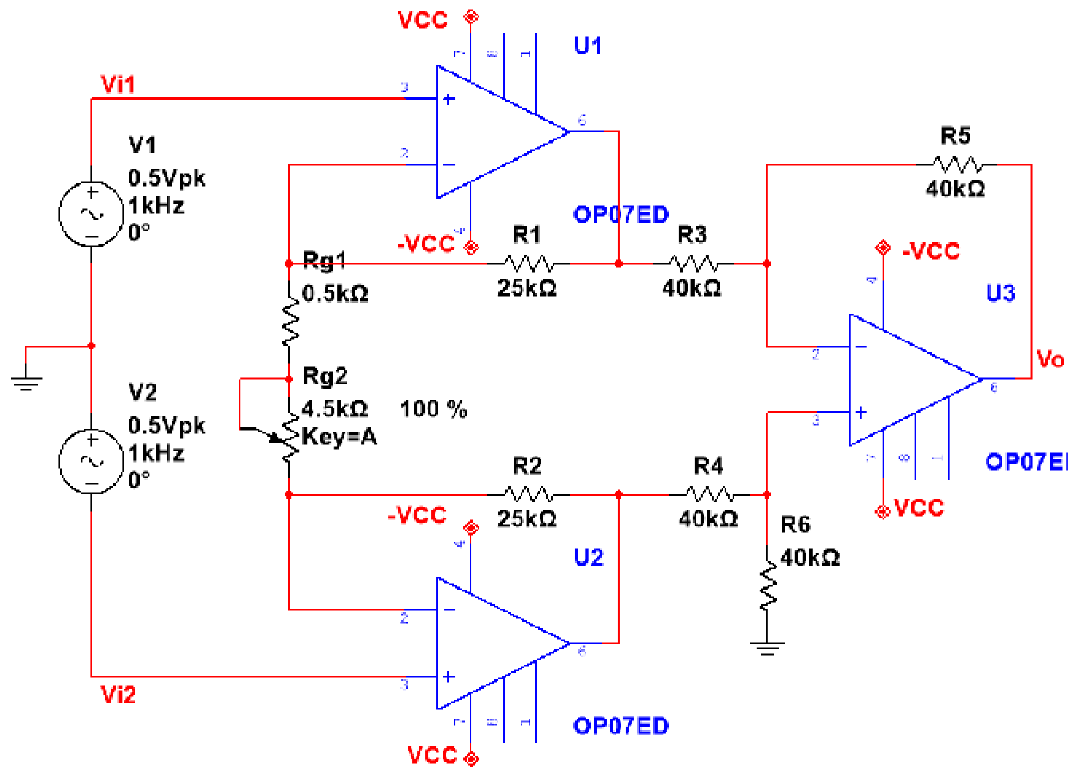
$$R_g = R_{g1} + R_{g2}$$

- 令$R_g = 5\text{k}\Omega$，对应最小增益-11



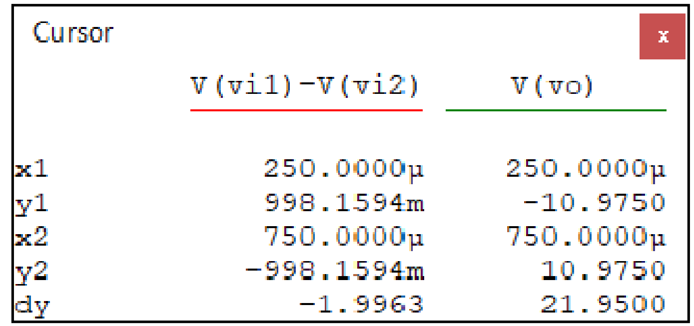
差模增益

- 差分信号
  - 幅度1V，频率1kHz
- 共模信号
  - 0V
- 瞬态仿真
- 仿真时间1ms



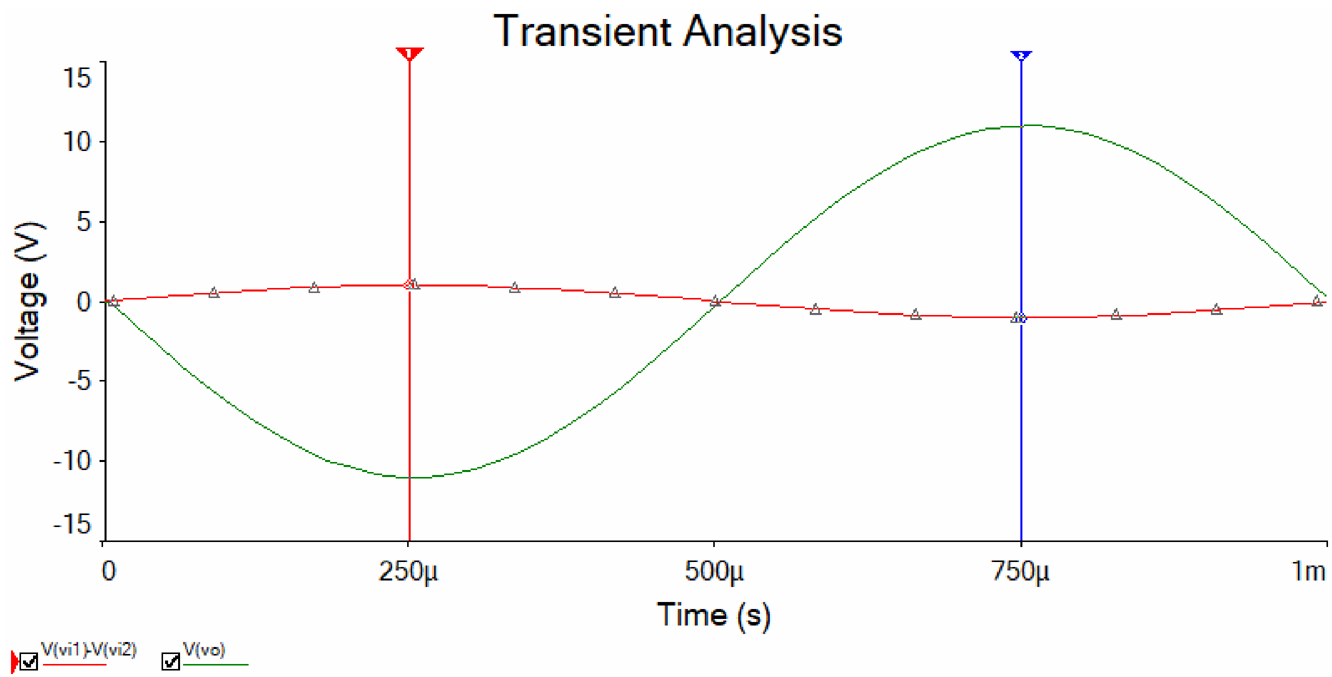
差模增益

$$\boxed{A_{vd} = -11}$$



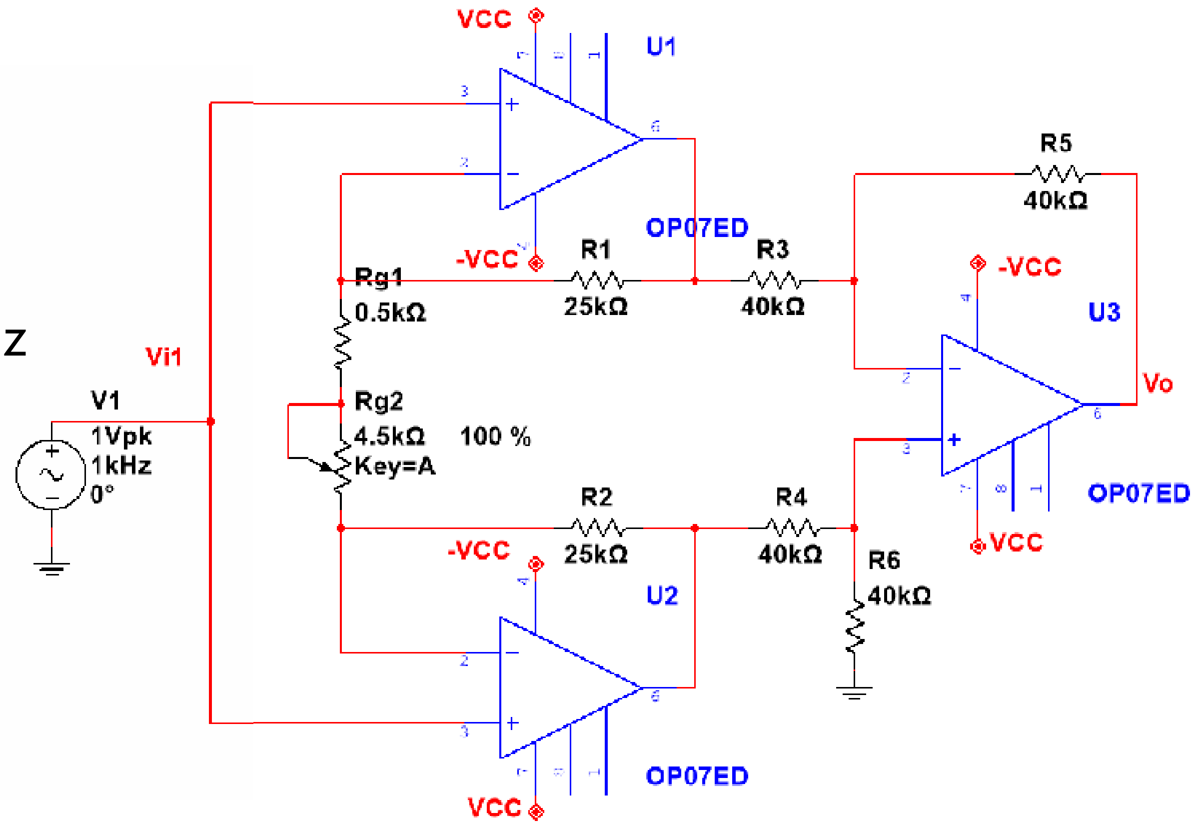
Cursor

	V(vi1)-V(vi2)	V(vo)
x1	250.0000µ	250.0000µ
y1	998.1594m	-10.9750
x2	750.0000µ	750.0000µ
y2	-998.1594m	10.9750
dy	-1.9963	21.9500



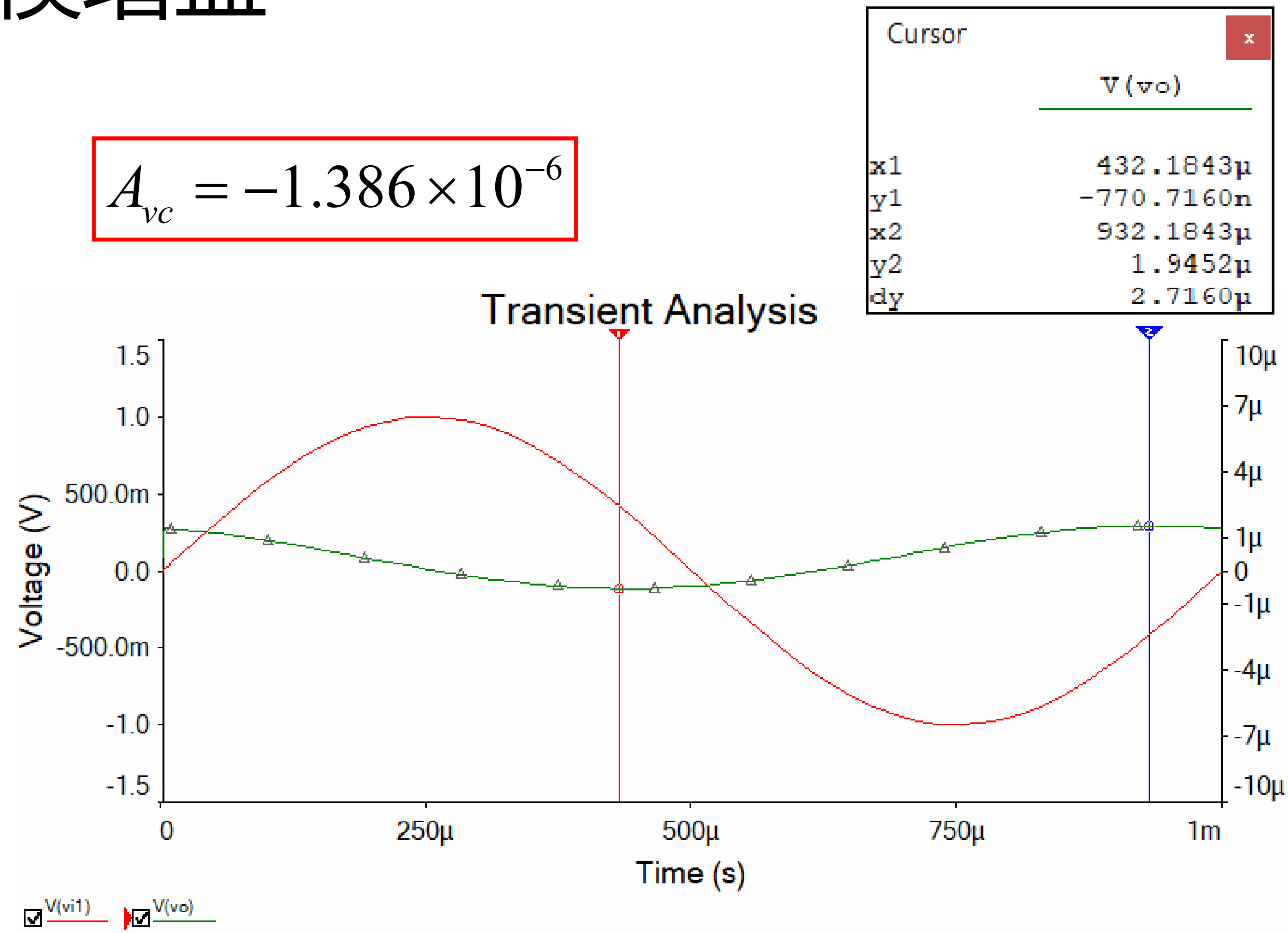
共模增益

- 差分信号
  - 0V
- 共模信号
  - 幅度1V，频率1kHz
- 瞬态仿真
- 仿真时间1ms



共模增益

$$A_{vc}=-1.386\times10^{-6}$$



$$CMRR=20\lg\left|\frac{A_{vd}}{A_{vc}}\right|=20\lg\left|\frac{11}{1.358\times10^{-6}}\right|=138dB$$