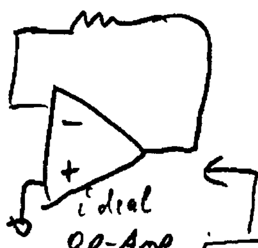
EECE 2412 : HW2 Solutions

Fall 2018

Prob. 1

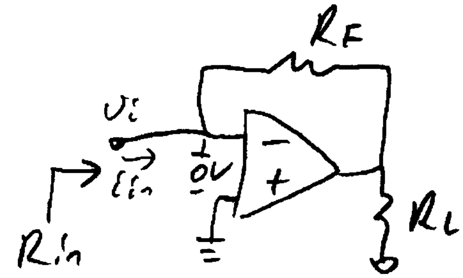
a) $i_{in} = \frac{0V - v_o}{R_F} \rightarrow \boxed{v_o = -R_F \cdot i_{in}}$

b)



$\boxed{R_o = 0}$

c)



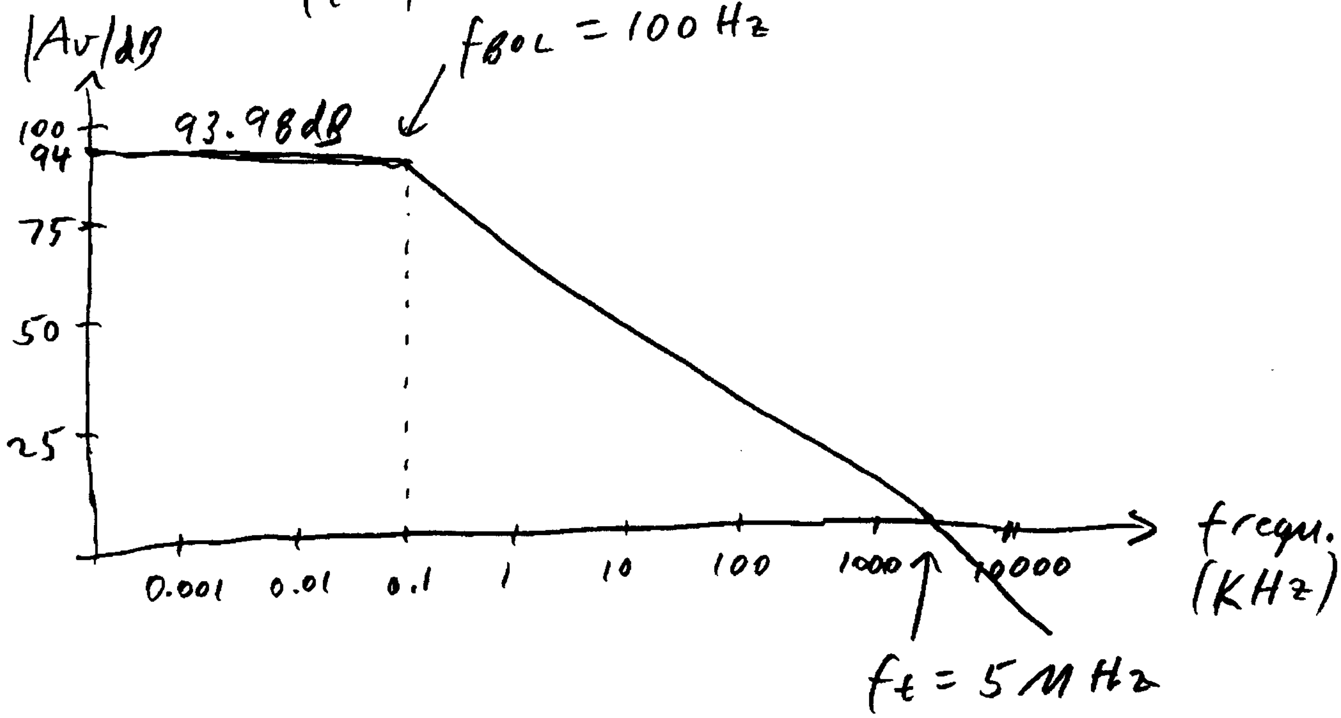
$R_{in} = \frac{v_i}{i_{in}} = \frac{0}{i_{in}} = \boxed{0 = R_{in}}$

d) ideal transresistance amplifier.

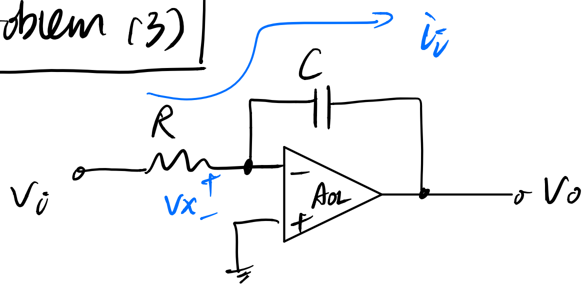
Prob. 2

$20 \cdot \log(50000) = 93.98\,dB$

$f_t = f_{BOL} \cdot A_{OOL} = 100 \cdot 50000 = 5\,MHz$



Problem (3)



(a) $i_i = \dfrac{V_i - V_x}{R} = \dfrac{V_x - V_o}{\frac{1}{sC}}$ ①

$V_o = -V_x \cdot A_{OL} \longrightarrow V_x = -\frac{1}{A_{OL}} \cdot V_o$

apply ② to ① :

$$\frac{1}{R}\left(V_i + \frac{1}{A_{OL}} V_o\right) = sC\left(-\frac{1}{A_{OL}} \cdot V_o - V_o\right)$$

$$V_o\left[\frac{1}{R} \cdot \frac{1}{A_{OL}} + sC\left(1 + \frac{1}{A_{OL}}\right)\right] = -\frac{1}{R} V_i$$

$$A_{CL}(s) = \frac{V_o}{V_i} = \frac{-\frac{1}{R}}{sC\left(1+\frac{1}{A_{OL}}\right) + \frac{1}{R} \cdot \frac{1}{A_{OL}}}$$

$$= -\frac{\frac{1}{sRC}}{1 + \frac{1}{A_{OL}} + \frac{1}{sRC} \cdot \frac{1}{A_{OL}}}$$

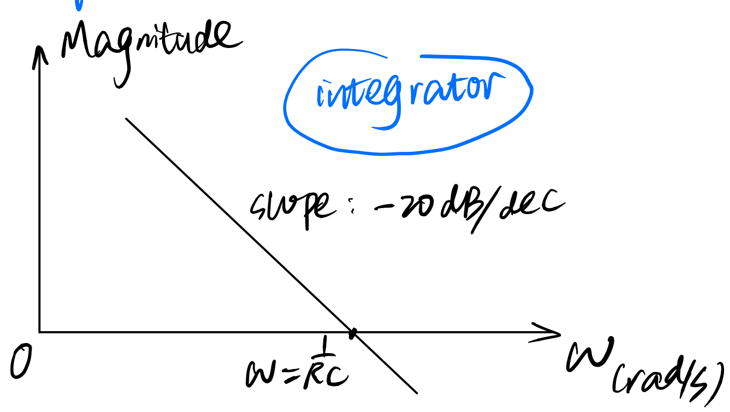
$$\boxed{A_{CL}(j\omega) = \frac{-\frac{1}{j\omega RC}}{1 + \frac{1}{A_{OL}} + \frac{1}{j\omega RC} \cdot \frac{1}{A_{OL}}}}$$

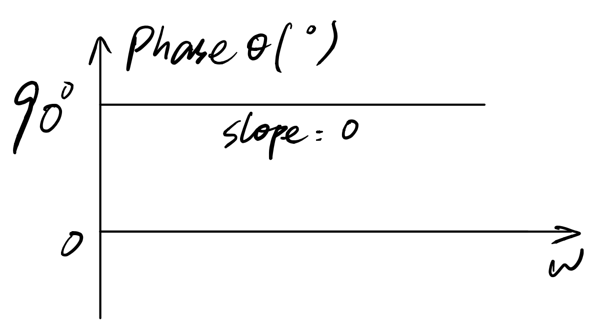
(b) $A_{OL} \to \infty$

$A_{CL}(j\omega) = -\frac{1}{j\omega RC}$

$$\begin{cases} 20\log\left|A_{CL}(j\omega)\right| = 20\log\frac{1}{\omega RC} = -20\log \omega RC \\ \theta = -\arctan\left(\frac{\omega RC}{0}\right) = -90^\circ \end{cases}$$

NOTE: eq 2.55 in textbook





(c)

$$A_{CL}(j\omega) = \frac{-\frac{1}{j\omega RC}}{1+\frac{1}{A_{OL}}+\frac{1}{j\omega RC}\cdot\frac{1}{A_{OL}}}$$

$\omega = 2\pi f = 2\pi\cdot 100 = 200\pi$ rad/s

$A_{OL} = 10^4$

$R = 50k\Omega = 50\times10^3\ \Omega$

$C = 50\ pF = 50\times10^{-12}\ F$

$$A_{CL}(j200\pi) = \frac{-\frac{1}{j200\pi\times50\times10^3\times50\times10^{-12}}}{1+\frac{1}{10^4}+\frac{1}{j200\pi\times50\times10^3\times50\times10^{-12}}\times\frac{1}{10^4}}$$

$$\boxed{= 635.2703\angle 93.6^\circ}$$

[For comparison, with ideal opamp ($A_{OL}=\infty$)

$A_{CL}(j200\pi) = 636.6198\angle 90^\circ$]

Output at 100 Hz:

$V_{out}(j200\pi) = A_{CL}(j200\pi)\cdot V_{in}(j200\pi)$

$= (635.2703\angle 93.6^\circ)\cdot(5mV\angle 0^\circ)$

$= 3.176\angle 93.6^\circ$ [V]

$V_{out}(t) = 3.176\cdot\sin(2\pi\cdot100t + 93.6^\circ)$

$\boxed{\text{output amplitude} = 3.176V}$

$\boxed{\text{Problem 4}}$ equ. 2.39 in the book: $f_t = A_{0CL} \cdot f_{BCL} = A_{0OL} \cdot f_{BOL}$

$$f_{3dB} = f_{BCL} = \frac{f_t}{A_{0CL}} = \frac{20 \times 10^6\ Hz}{100} = \boxed{200\ kHz = f_{BCL}}$$

Equ. 2.37 in the book provides the closed-loop response:

$$A_{CL}(f) = \frac{A_{0CL}}{1 + j\frac{f}{f_{BCL}}} = \frac{100}{1 + j\frac{f}{200 \times 10^3}} \xrightarrow{\text{Phase:}} \angle A_{CL}(f) = \tan^{-1}\left(\frac{0}{100}\right) - \tan^{-1}\left(\frac{f/f_{BCL}}{1}\right)$$

$$\angle A_{CL}(f) = 0 - \tan^{-1}\left(\frac{f/f_{BCL}}{1}\right) = -\tan^{-1}\left(\frac{f}{f_{BCL}}\right)$$

$$-6^\circ = -\tan^{-1}\left(\frac{f_1}{200 \times 10^3}\right) \longrightarrow \boxed{f_1 = 21.02\ kHz}$$ (−6° phase shift)

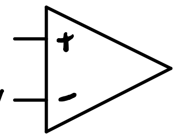
$$-84^\circ = -\tan^{-1}\left(f_2 / 200 \times 10^3\right) \longrightarrow \boxed{f_2 = 1.903\ MHz}$$ (−84° phase shift)

Problem (5)

$$CMRR = \frac{|A_{dm}|}{|A_{cm}|} = 85\,dB \quad , \quad |A_{dm}| = 102\,dB$$

$v_1 = 110\mu V$

$V_2 = 40\mu V$



(a) $V_{in,dm} = V_1 - V_2 = 110\mu V - 40\mu V = \boxed{70\ \mu V}$

(b) $V_{in,cm} = \frac{1}{2}(V_1+V_2) = \frac{1}{2}(110\mu V + 40\mu V) = \boxed{75\ \mu V}$

(c) $|A_{dm}| = 102\,dB \longrightarrow 10^{\left(\frac{102}{20}\right)} = 125892.54$

$CMRR = 85\,dB \longrightarrow 10^{\left(\frac{85}{20}\right)} = 17782.79$

$|A_{cm}| = \frac{CMRR}{|A_{dm}|} = 102 - 85 = 17\,dB \longrightarrow 10^{\left(\frac{17}{20}\right)} = 7.09$

$$\boxed{|A_{cm}| = 7.09}$$

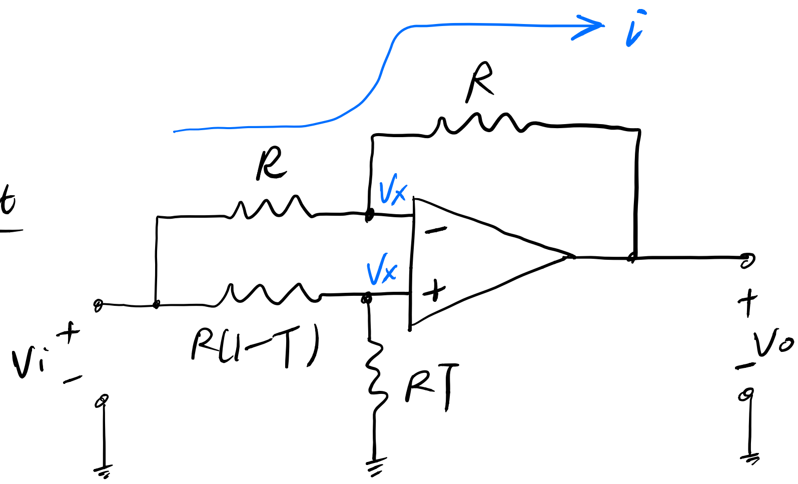
$$V_{out} = V_{in,cm} \cdot |A_{cm}| + V_{in,dm} |A_{dm}|$$

$$= 75\mu V \times 7.09 + 70\mu V \times 125892.54$$

$$\boxed{V_{out} = 8.81301\ V}$$

Problem (b)

equivalent circuit



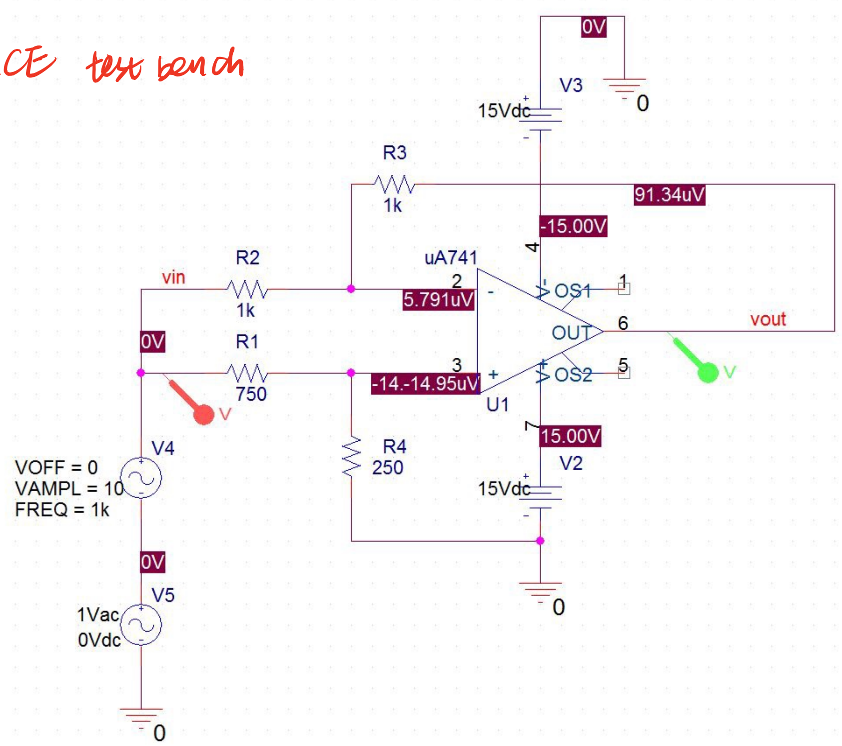
$$\begin{cases} i = \dfrac{V_i - V_x}{\cancel{R}} = \dfrac{V_x - V_o}{\cancel{R}} \\ V_x = \dfrac{RT}{R} \cdot V_i = T \cdot V_i \end{cases}$$

$$V_i - TV_i = TV_i - V_o$$

$$V_o = (2T - 1) \cdot V_i$$

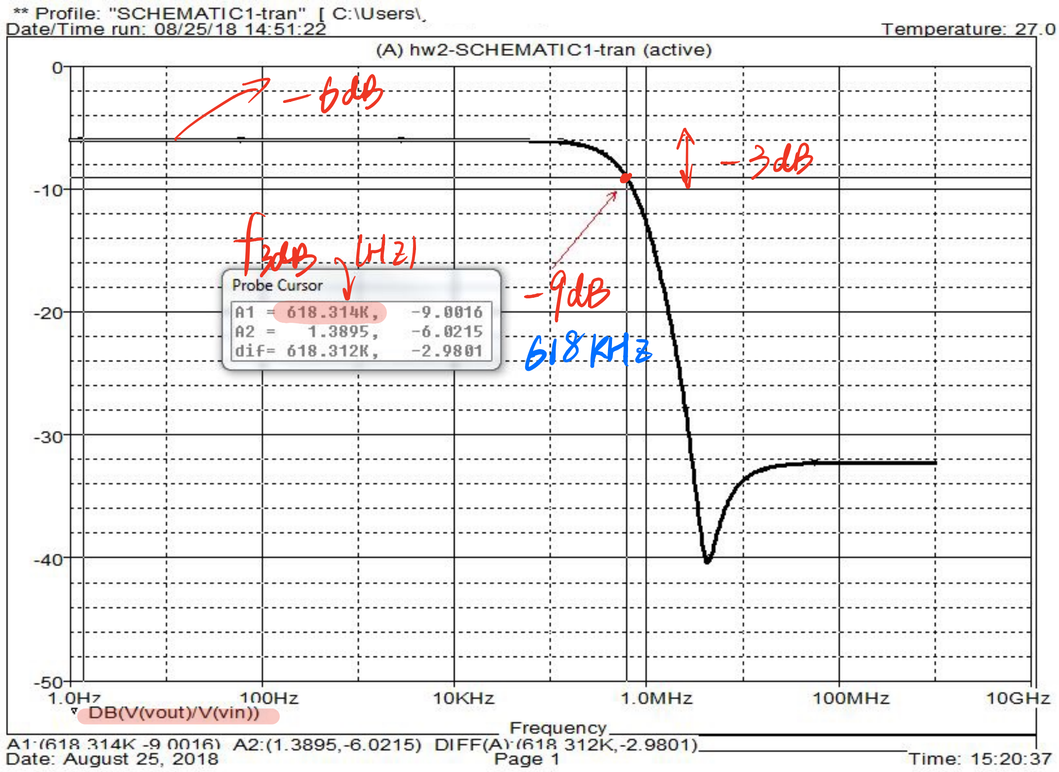
$$\boxed{A_V = \frac{V_o}{V_i} = 2T - 1} \xrightarrow{T = 0.25} A_V = -0.5 \rightarrow \boxed{-6dB}$$

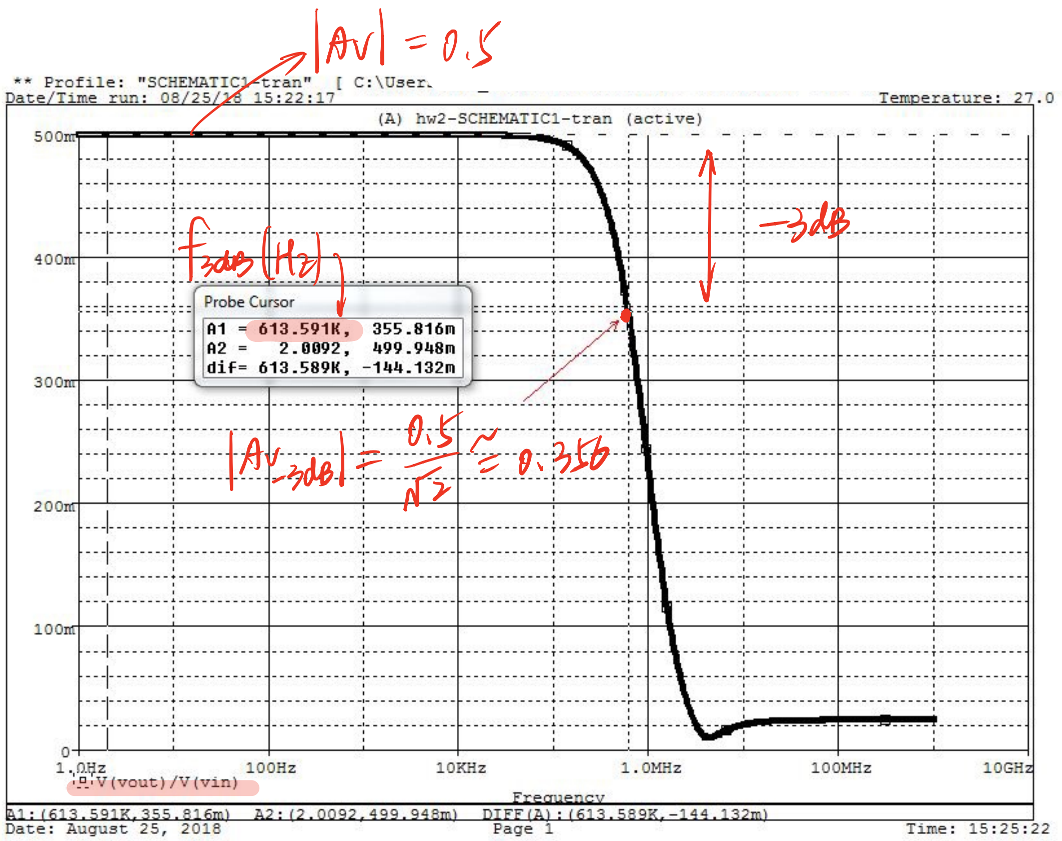
PSPICE test bench



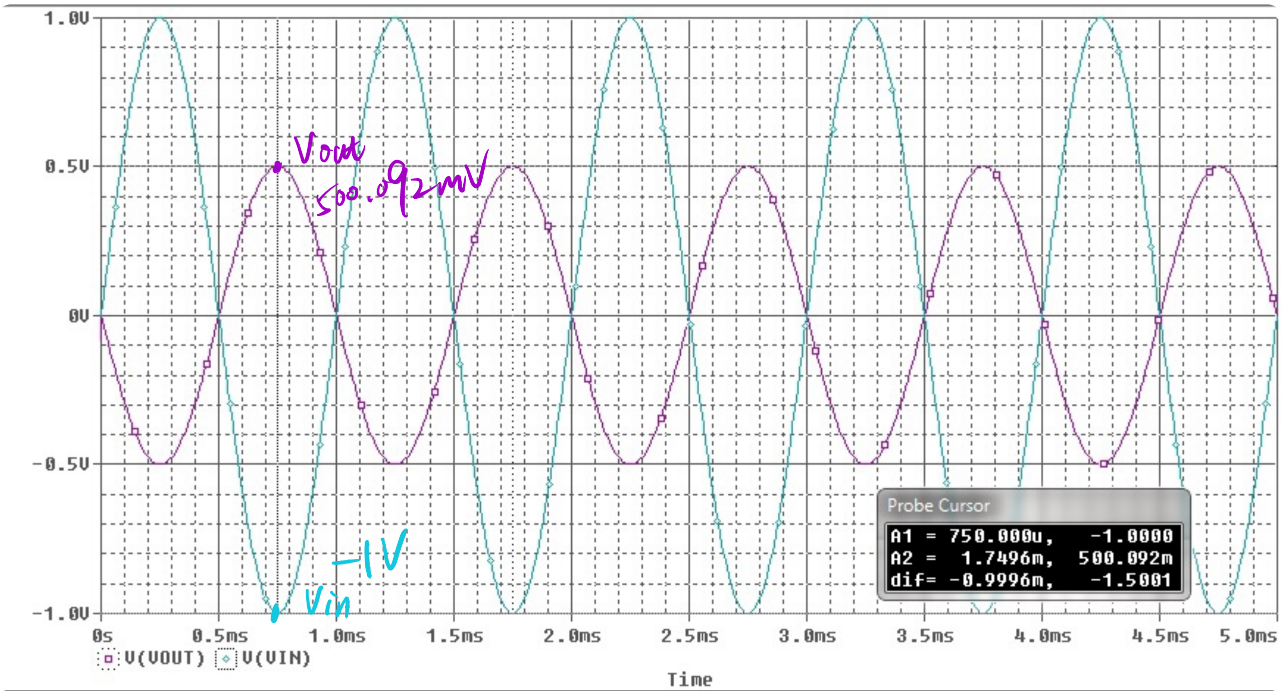
(a)

Voltage gain in dB vs. frequency





(b) Transient input/output voltages with a sinusoid always input signal with an amplitude of 1V @ 1kHz

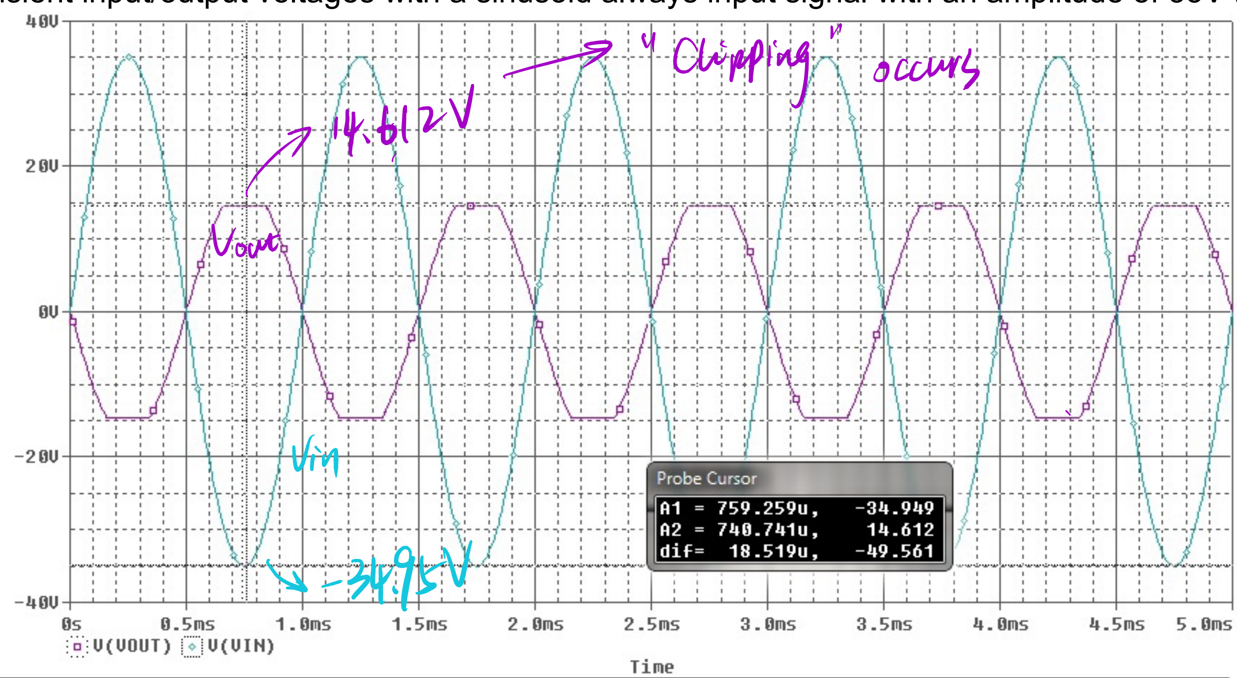


$$A_V = \frac{-1V}{0.500092V} = -0.50092$$

expected $A_V = 2T - 1 = -0.5$

Theory and simulation results match.

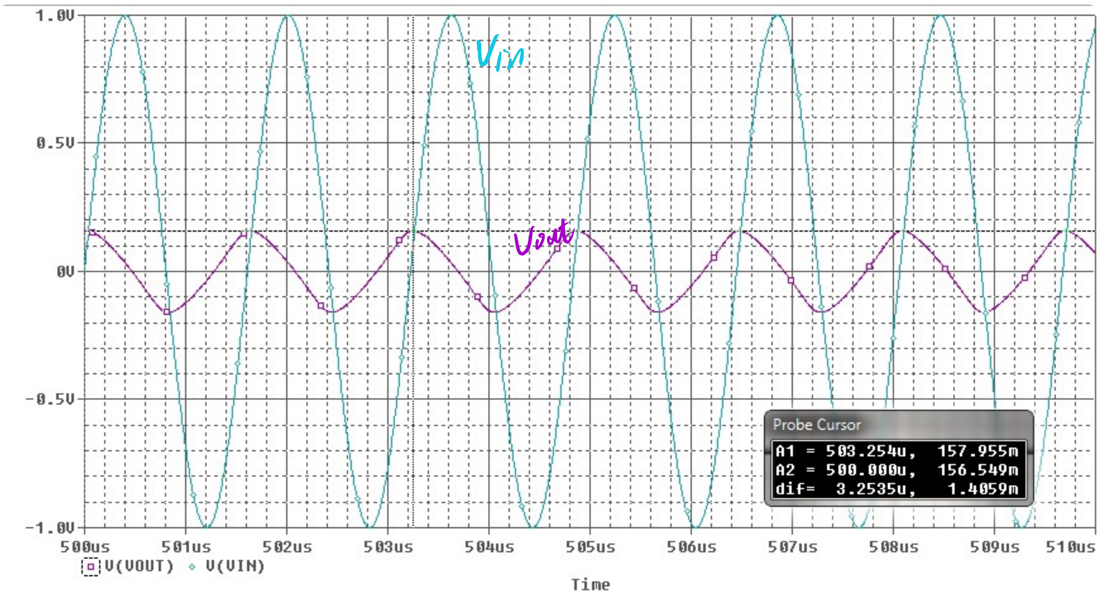
(C) Transient input/output voltages with a sinusoid always input signal with an amplitude of 35V @ 1kHz



Signal "Vout" gets clipped as a result of "signal can never reach beyond the supply voltage (±15V)"

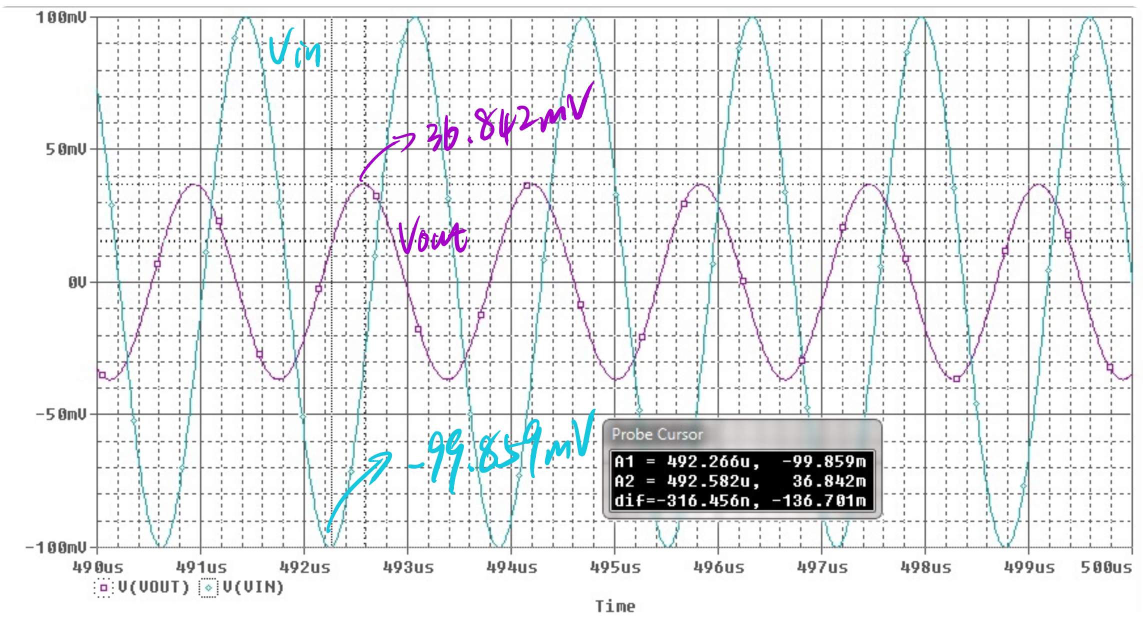
saturation

(d) Transient input/output voltages with a sinusoid always input signal with an amplitude of 1V @ 613kHz



* The output signal is almost equal to trangle wave as a result of the slew rate limits from the op-amp.

(e) Transient input/output voltages with a sinusoid always input signal with an amplitude of 0.1V @ 613kHz



$V_{in(p\text{-}p)} = 199.718\,mV$

$V_{out(p\text{-}p)} = 73.684\,mV$

$A_v = \frac{V_{out(p\text{-}p)}}{V_{in(p\text{-}p)}} \cong 0.369$

$\boxed{\text{NOTES}}$

$f_{3dB} = 613\,kHz$

$A_{3dB} = \frac{A_{DC}}{\sqrt{2}} = \frac{0.5}{\sqrt{2}} = 0.353$

} Simulation results agree with theoretical expectation