Pre-Lab 5: Operational Amplifiers Part 3

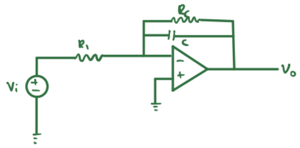
ECEN 325 - 511

TA: Zhiyong Zhang

Due Date: October 12, 2021

Calculations

Lossy Integrator



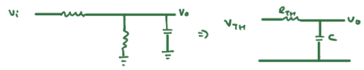
we have $R_2 = 22k$, $C = 220nF$, $\frac{V_o(s)}{V_i(s)} = 22$ (low)

$\hookrightarrow V_c(t) = V_c(\infty) + (V_c(0) - V_c(\infty))e^{-t/\tau}$

$\tau \rightarrow$ constant time

$V_c(t) =$ voltage accross capacitor

To get thevenin voltage accross C we have



voltage accross R_2 will be V_{TH} and $R_{TH} = R_1 \| R_2$

$$V_{TH} = \frac{R_2}{R_1+R_2} V_i \quad -①$$

$V_c(\infty) = 0$

$V_c(0) = V_{TH}$

$V_o(t) = V_{TH} e^{-t/\tau}$

we have $\tau = R_{TH} C = \frac{R_1 R_2 C}{R_1 + R_2} \quad -②$

1) $$\boxed{V_o(t) = \frac{R_2}{R_1+R_2} e^{-t\left(\frac{R_1+R_2}{R_1 R_2 C}\right)}}$$

2) Voltage Gain $\frac{V_o(s)}{V_i(s)} = \frac{-R_2 \| Z_c}{R_1}$

$$= \frac{R_2 Z_c}{R_2 + Z_c} \cdot \frac{1}{R_1}$$

$$= \frac{-R_2}{R_1}\left(\frac{1/cs}{R_2 + \frac{1}{cs}}\right) = \frac{-R_2}{R_1}\left(1 / R_2 Cs + 1\right)$$

$$\boxed{\frac{V_o(s)}{V_i(s)} = \frac{-R_2}{R_1}}$$ finite gain

now $-22 = -R_2/R_1$

$R_2 = 22k\Omega$

$$\boxed{R_1 = 1k\Omega}$$

the 3dB frequence $= \frac{1}{\tau} = \frac{R_1 + R_2}{R_1 R_2 C}$

$$= \frac{1k\Omega + 22k\Omega}{22k\Omega * 1k\Omega \times 220nF}$$

$$= \boxed{4.75\,kHz}$$

3) $$\frac{V_o(s)}{V_i(s)} = \frac{-R_2}{R_1}\left(\frac{1}{R_2 Sc + 1}\right)$$

$$\frac{V_o(s)}{V_i(s)} = \frac{-22k\Omega}{1k\Omega}\left(\frac{1}{22k\Omega\, s\, 220nF + 1}\right)$$

$$= \frac{-22}{4.84 \times 10^{-3} s + 1} = \frac{-22}{\frac{s}{206.61} + 1} = \frac{-22}{1 + \frac{s}{206.61}}$$

compare w/ $\frac{-k}{1 + s/\omega}$ $\quad f = 206.61$, $k = 22$

only one pole at 206.61

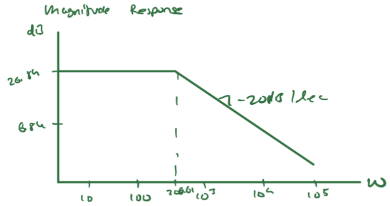
so $|T_o(s)| = +20\log(22)$

$\lim |T_o(s)| = +20\log(22) = 26.85$

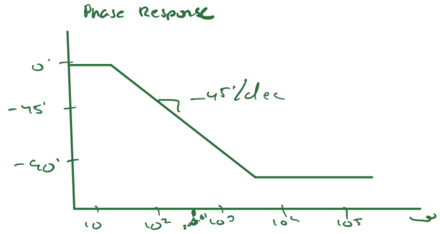
phase $[T(s)] = -\tan^{-1}\left(\frac{s}{206.61}\right)$

$\lim_{s \to 0}$ phase $[T(s)] = -\tan^{-1}\left(\frac{0}{206.61}\right) = 0°$

Magnitude Response



Phase Response



4) $\frac{V_o(s)}{V_i(s)} = \frac{22}{1+\frac{s}{206.61}} = \frac{22}{\sqrt{1+\frac{\omega^2}{206.61^2}}} \angle -\tan^{-1}(\omega/206.61)$

at $\omega = 2\pi 1000t$

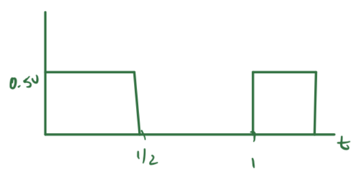
$= \frac{22}{\sqrt{1+\frac{(2000\pi)^2}{(206.61)^2}}} \angle -\tan^{-1}\left(\frac{2000\pi}{206.61}\right) = -0.723 \angle -88.11$

$V_o = -0.723 \angle -88.11 \times 0.5 \angle 0^\circ$

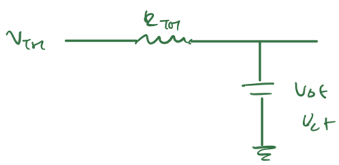
$V_o = -.3615 \angle -88.11$

$$\boxed{V_o(t) = -0.3615 \sin(2\pi 1000t - 88.11)}$$

5) Given square wave



From thevenin circuit



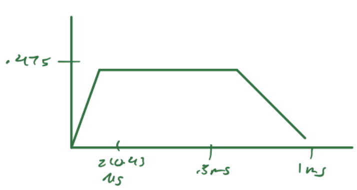
$V_{TH} = \frac{R_2}{R_1+R_2} V_i = \frac{22}{1+22} V_i \cong 0.95 V_i$

$R_{TH} = \frac{R_1 R_2}{R_1+R_2} = 0.95\ k\Omega$

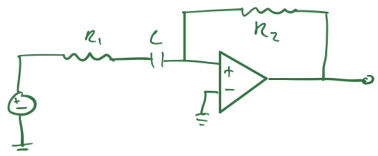
$\tau = R_{TH} C = 0.95 \times 220nF = 210.43\ \mu s$

since $V_i = 0.5V$ $\quad V_{TH} = 0.9 \times 0.5V$
$= 0.475V = 475mV$

$V_o(t) = (V_{TH} - V_{TH} e^{-t/\tau}) \quad \tau = 210.43\ \mu s$



Pseudo Differentiator



we have gain = -22
$R_1 = 1k\Omega$
$C = 33\,nF$

As $t \to \infty$ $V_o = 0$ $T\,(R_1 + R_2)C$

$$V_o(t) = V_o(t)\left(\frac{R_2}{R_1+R_2}\right) \quad \text{for } t=0 \text{ to } \tau$$

$$V_o(t) = V_i(t) \times R_2/R_1+R_2 \quad \text{for } t=0 \text{ to } \tau$$

$$V_o(t) = V_i'(t) \times \frac{R_2}{R_1+R_2}\, e^{-t/\tau_1}$$

$$\boxed{V_o(t) = V_i(t)\,\frac{R_2}{R_1+R_2}\, e^{-t/(R_1+R_2)C}}$$

for high freq $\omega \to \infty$ $i_e = \frac{1}{sc} = 0$ and C acts as a short circuit

$$\frac{V_2}{V_1} = A_v = -R_2/R_1 = -22 \quad , \quad R_2 = 22 \times 1k = 22k\Omega$$

$$\left|\frac{V_o(s)}{V_i(s)}\right| = \frac{R_2}{R_2 + (R_1 + 1/cs)} = \frac{R_2 Cs}{1 + C(R_2+R_1)s}$$

$$= \frac{7.26 \times 10^{-4}\, s}{1 + 7.59 \times 10^{-4} s} = 7.26 \times 10^{-4}\,\frac{s}{1 + \frac{s}{1317.5}}$$

here the transfer function has zero at 1317.5 and pole at 0

3dB freq at 1317.3 rad/sec

$$\frac{1}{\tau} = (R_1 + R_2)C$$

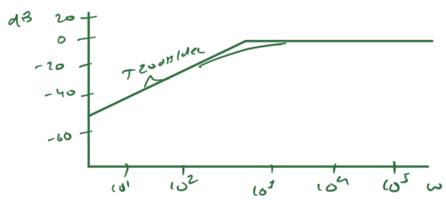
$$= (23k)(33nF) = \boxed{7.59 \times 10^{-4}\ Hz}$$

for magnitude: $\lim_{\omega \to 0} \left|\frac{V_o(s)}{V_i(s)}\right| = 20\log(7.26 \times 10^{-4})$

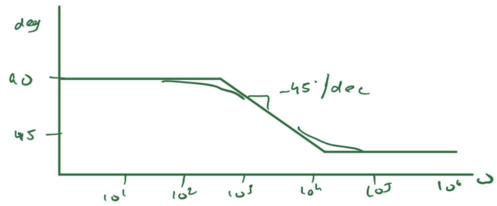
$$= \underline{-62.78\ dB}$$

for phase : $\lim_{\omega \to 0} \angle \frac{V_o(s)}{V_i(s)} = \tan^{-1}\left(\frac{0}{0}\right) - \tan^{-1}\left(\frac{0}{1317.3}\right) = 90^\circ$

magnitude Resp



phase



4) $V_i = 0.1 \sin(2\pi 1000 t)$

$V_i = 0.1 \angle 0°$ $\rightarrow$ transfer func. 1317.5 Hz

$$\frac{V_o(1317.5)}{V_i(1317.5)} = \frac{7.26 \times 10^{-4} \times 2000\pi j}{1 + 7.54 \times 10^{-4} \times 2000\pi j}$$

$$= 0.936$$

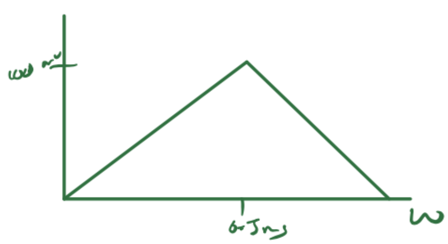
$$\angle \frac{V_o}{V_i} = \tan^{-1}\left(\frac{7.26 \times 10^{-4} \times 2000\pi}{0}\right) - \tan^{-1}\left(\frac{7.54 \times 10^{-4} \times 2000\pi}{1}\right)$$

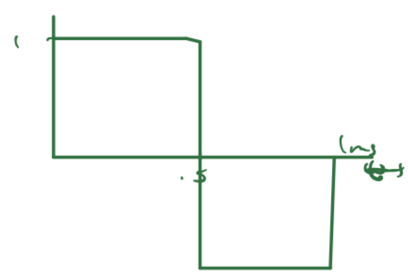
$$= 11.84$$

$$V_o = 0.0936 \angle 11.84$$

$$= \boxed{0.0936 \sin(2\pi 1000 t + 11.84)}$$

5)





Finite GBW Limitations

1) gain = 23 $R_1 = 1k\Omega$

gain $= 1 + \frac{R_2}{R}$

so $\boxed{R_2 = 22k\Omega}$

gain = 57 $57 = 1 + \frac{R_2}{1k\Omega}$

$\boxed{R_2 = 56k\Omega}$

gain for 83 $83 = 1 + \frac{R_2}{1k\Omega}$

$\boxed{R_2 = 82k\Omega}$

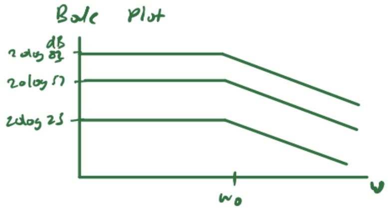
2) $\frac{V_o}{V_i} = \frac{G_0}{1\ s/\omega_0}$

for 23 $\rightarrow \frac{V_o}{V_i} = \frac{23}{1 + \frac{s}{\omega_0}}$

for 57 $\Rightarrow \frac{V_o}{V_i} = \frac{57}{1 + \frac{s}{\omega_0}}$

for 83 $\rightarrow \frac{V_o}{V_i} = \frac{83}{1 + \frac{s}{\omega_0}}$, phase resp. $= -\tan^{-1}\left(\frac{\omega}{\omega_0}\right)$

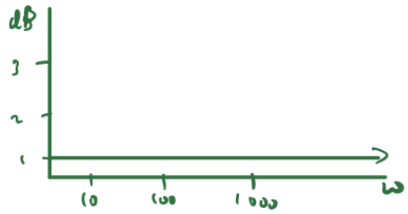
Bode Plot



slew rate limitation

from circuit $\frac{V_o}{V_i} = 1$

Bode Plot



Here slew rate = 0.5V/μs

$V_{in} = 1V$

$V_{in} = \sin \omega t = V_o$

$\frac{dV_o}{dt} = \omega \cos \omega t \quad = \quad 0.5\,V/\mu(s) = 2\pi f (1)$

$f = \frac{0.5}{2\pi} = \frac{0.5 \times 10^6}{2\pi} = \boxed{79.58\,kHz}$

slew rate = 0.5 V/μs

$V_{max} = ?$

$f = 75\,kHz$

$0.5\,V/\mu s = 2\pi\, 75k\, V_m$

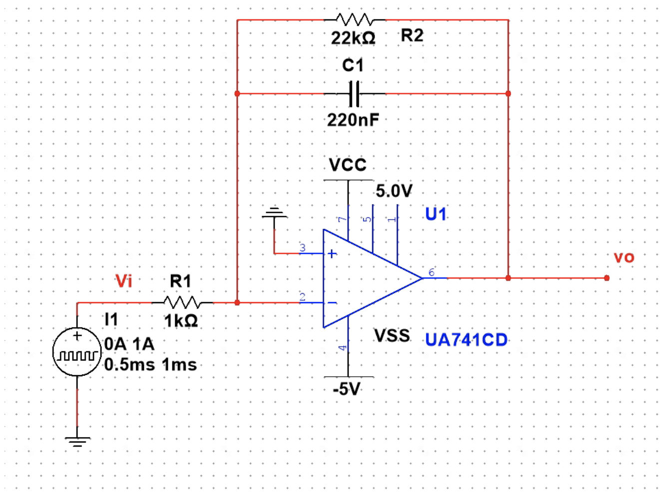
$V_m = \frac{0.5 \times 10^6}{2\pi \times 75k}$

$\boxed{V_m = 1.0610}$

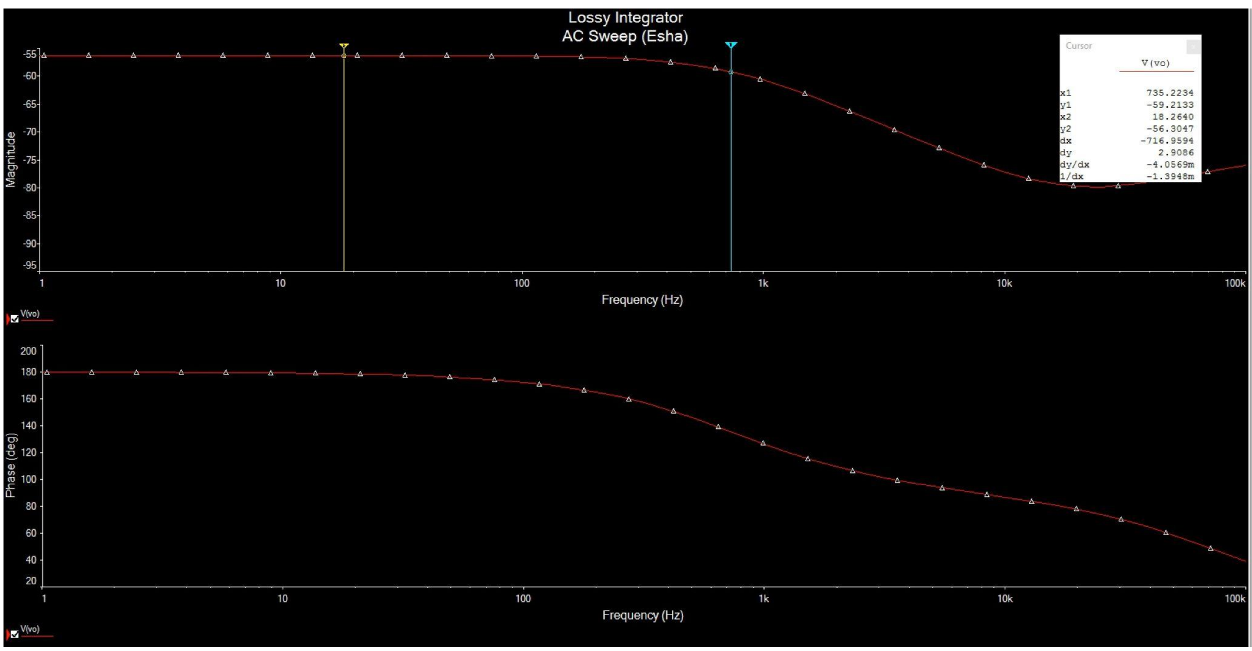
Simulations (on Multisim)

Lossy Integrator

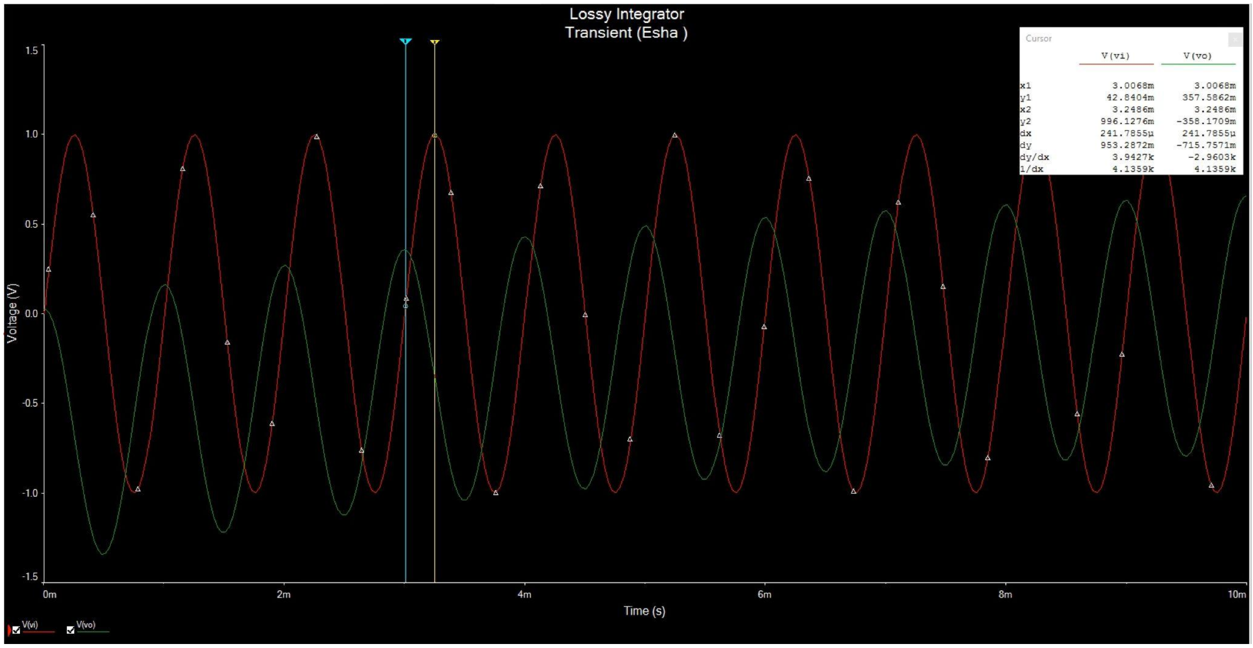
Schematic



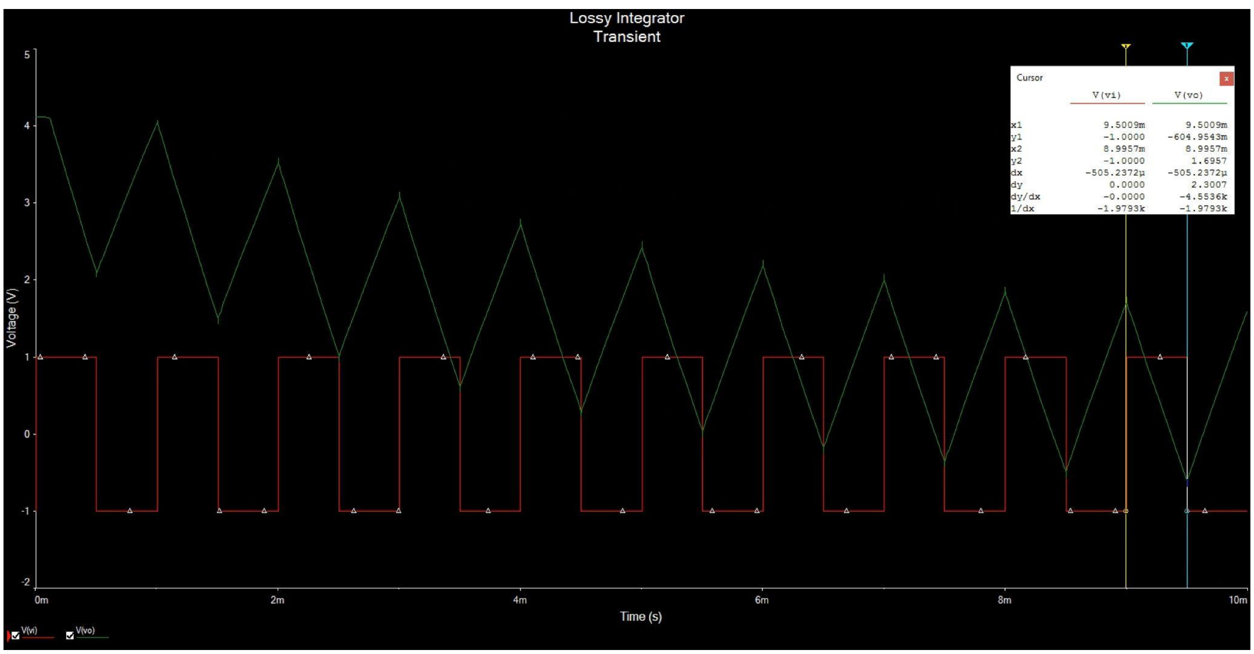
Bode



Sin Transient

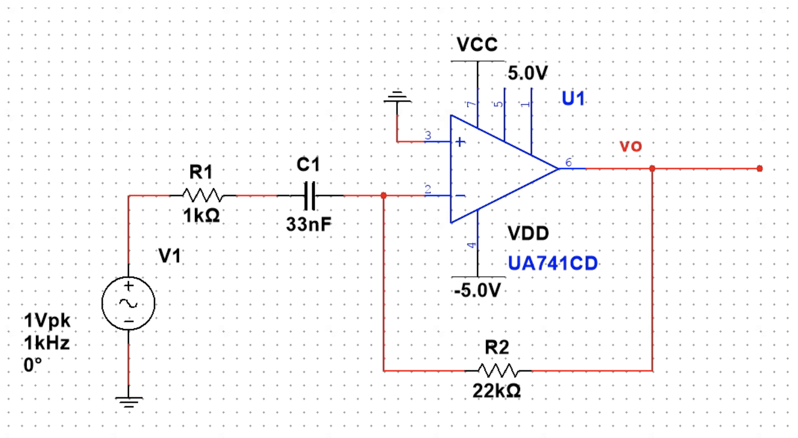


Square Transient

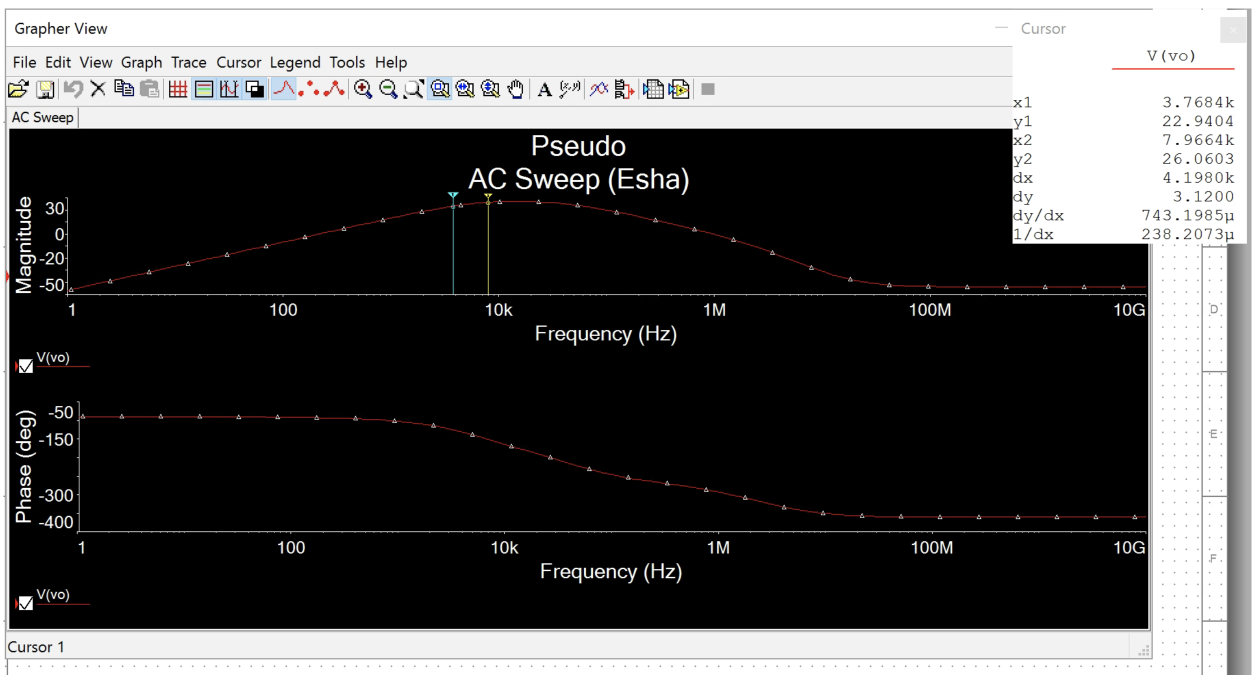


Psuedo Differentiator

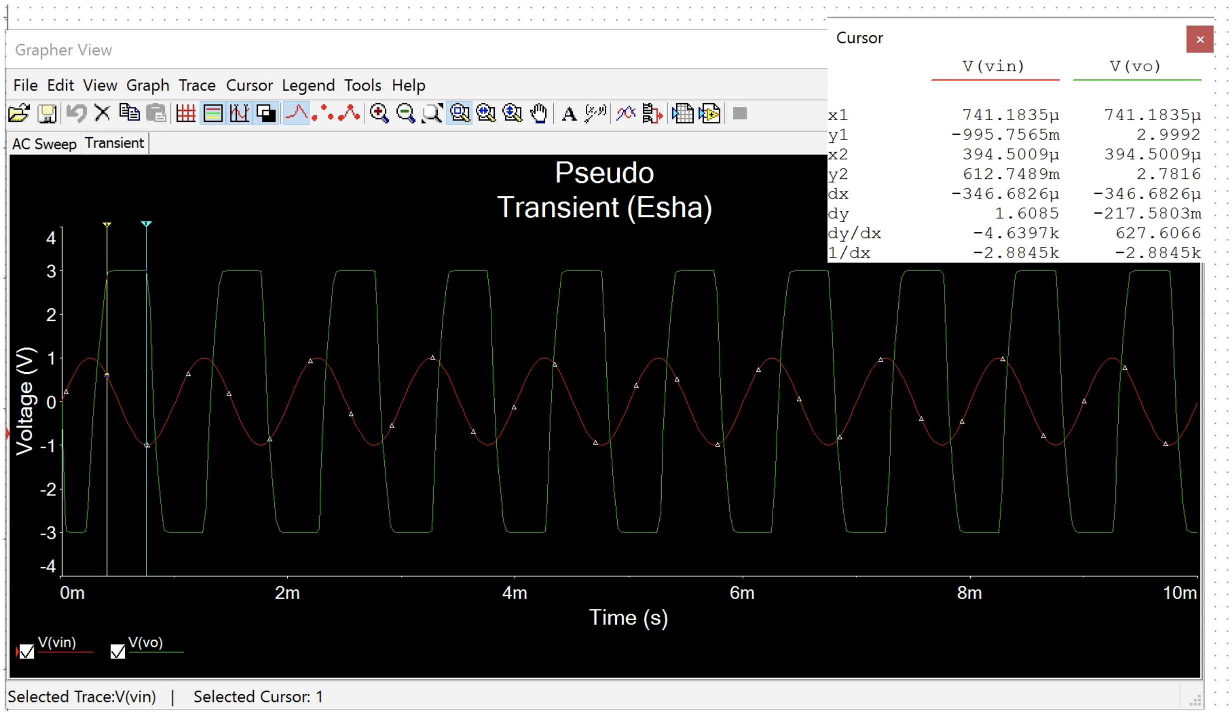
Schematic



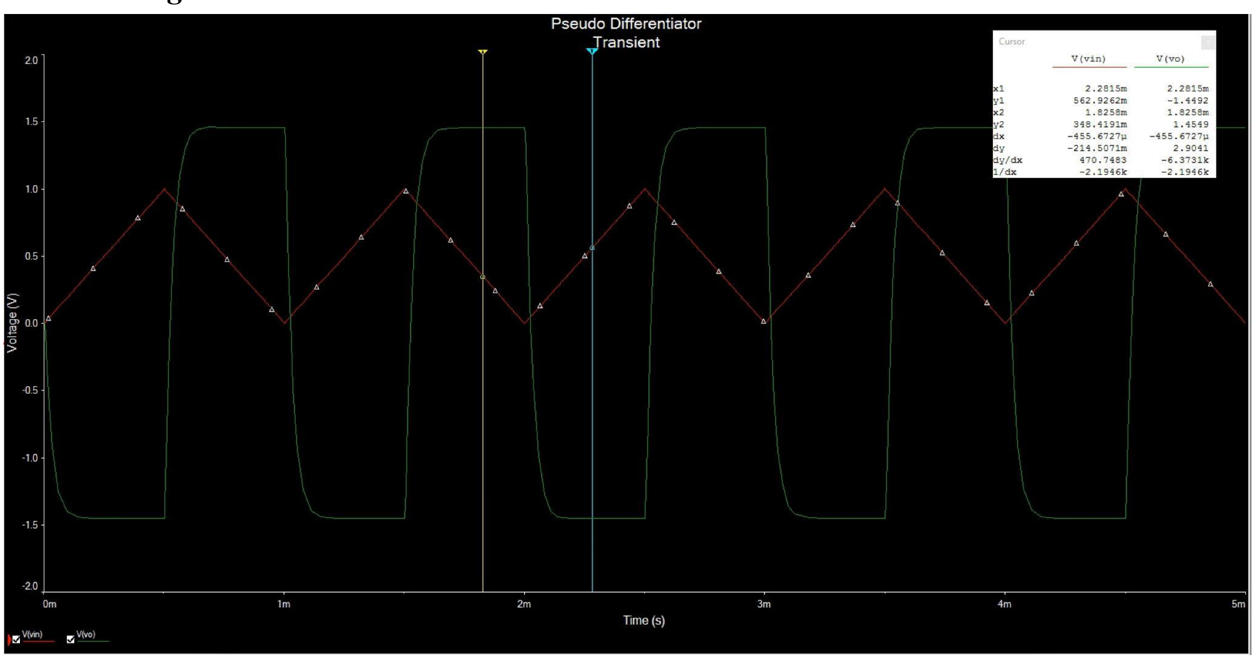
Bode



Sin Transient

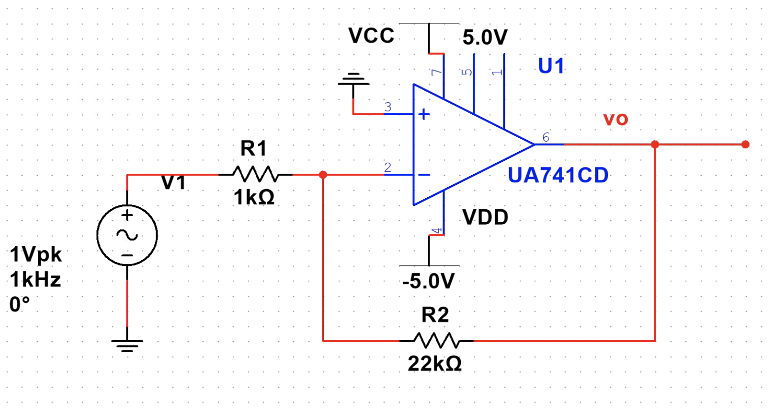


Triangle Transient

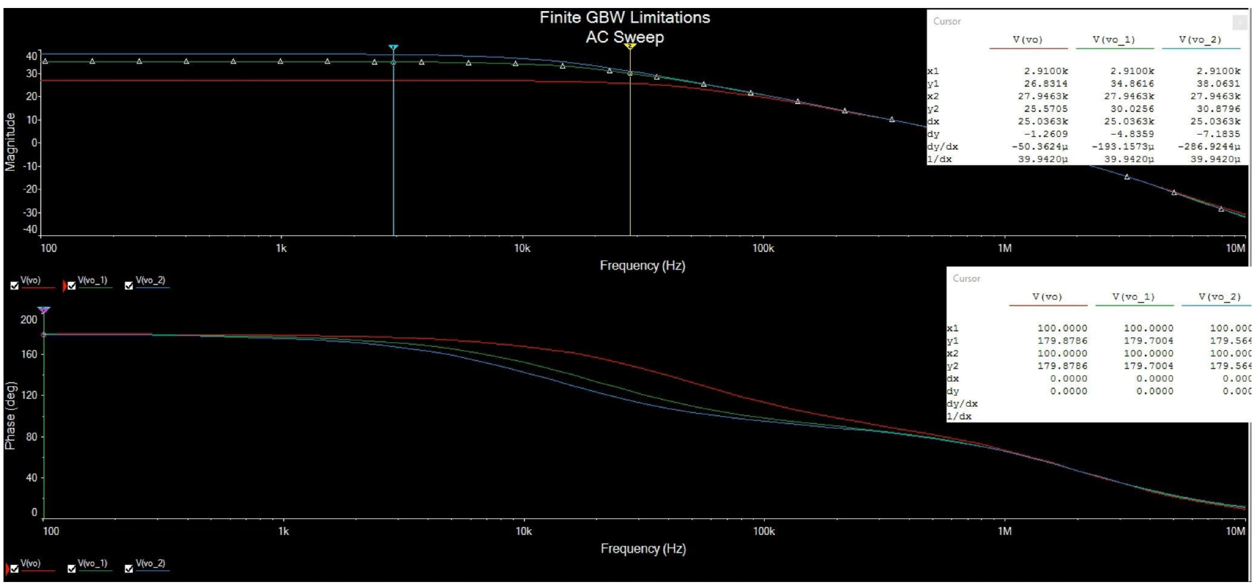


Finite GBW Limitations

Schematic

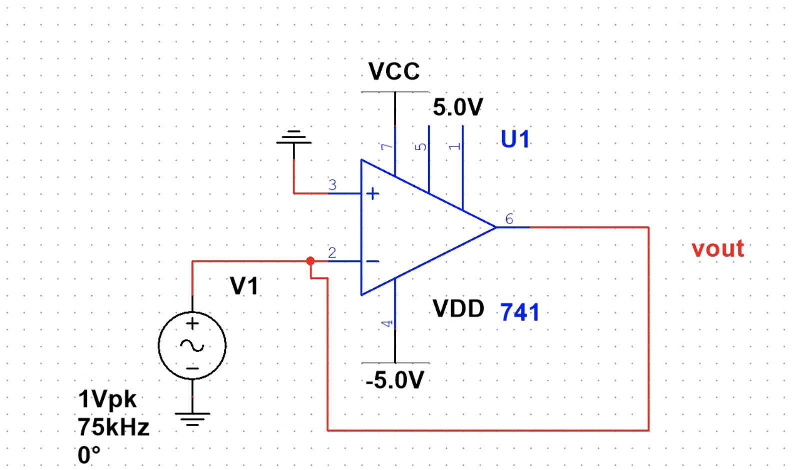


Bode

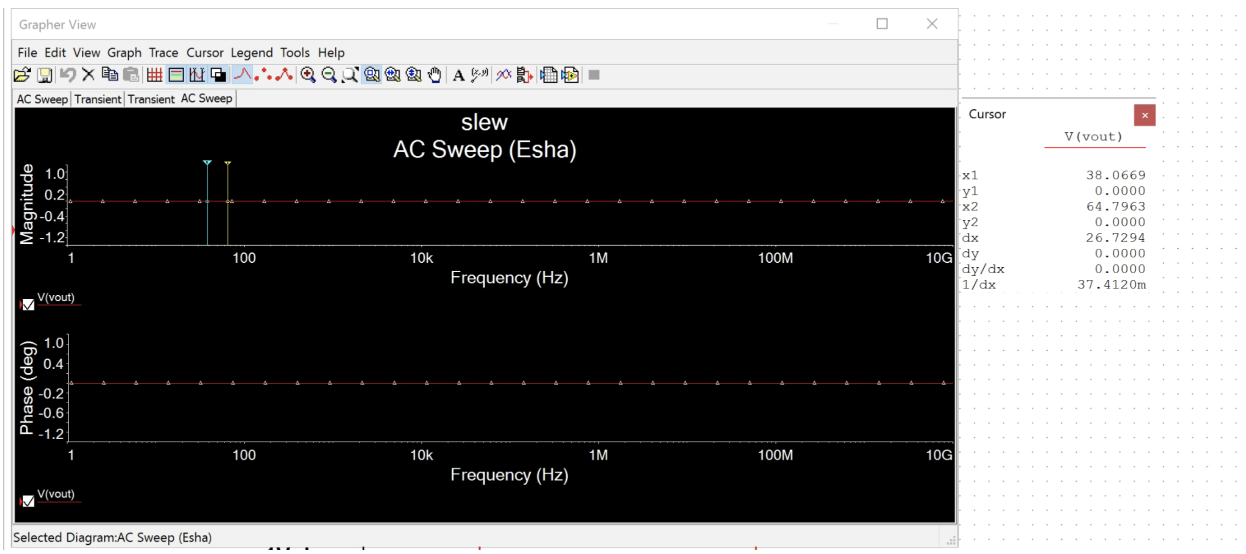


Slew Rate Limitations

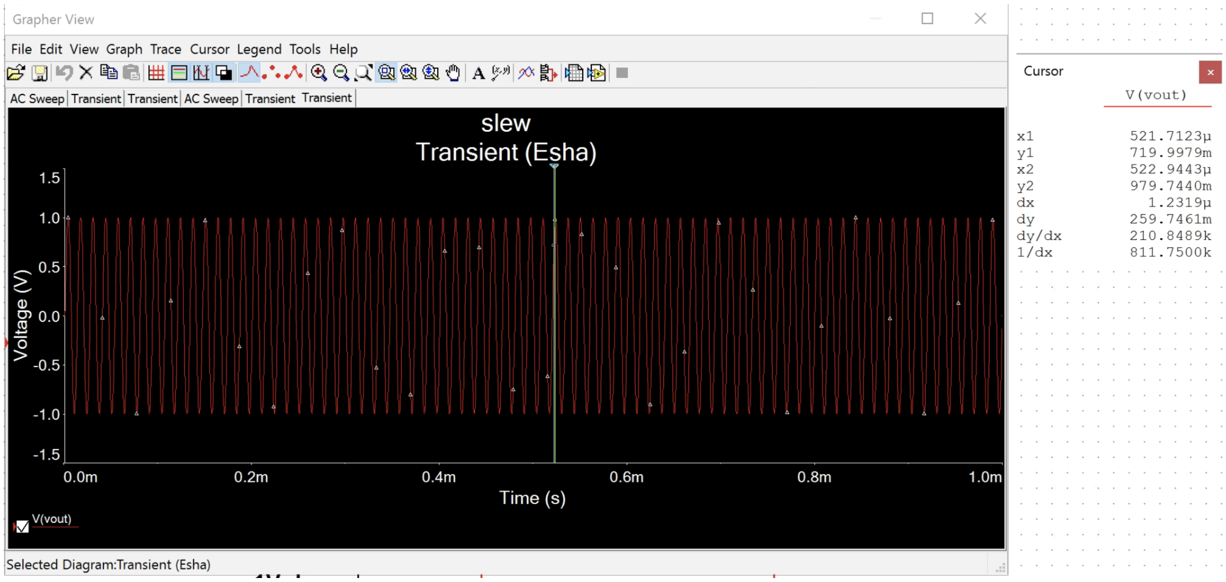
Schematic



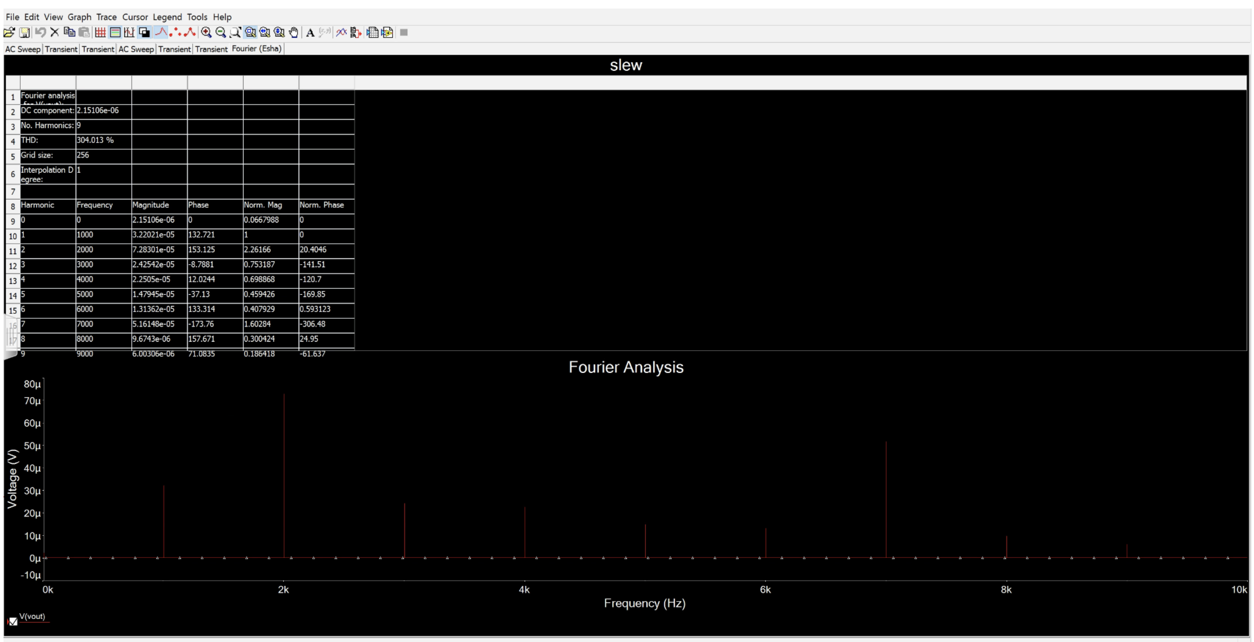
Bode



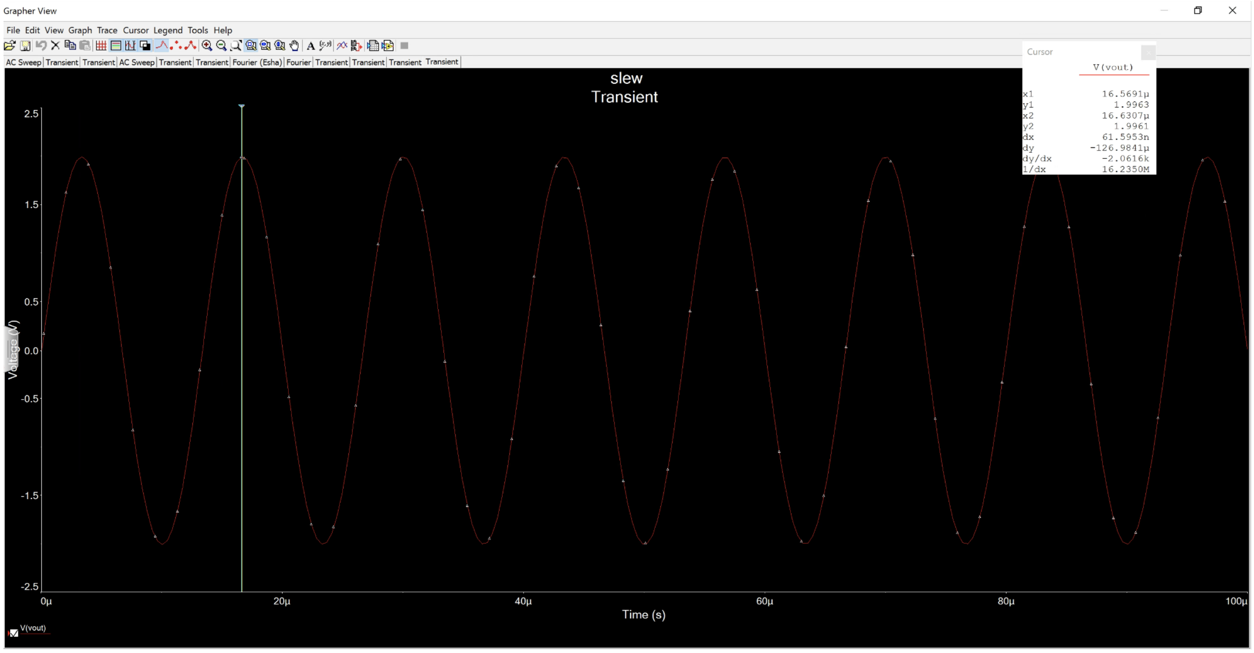
Sin Transient 75K 1V



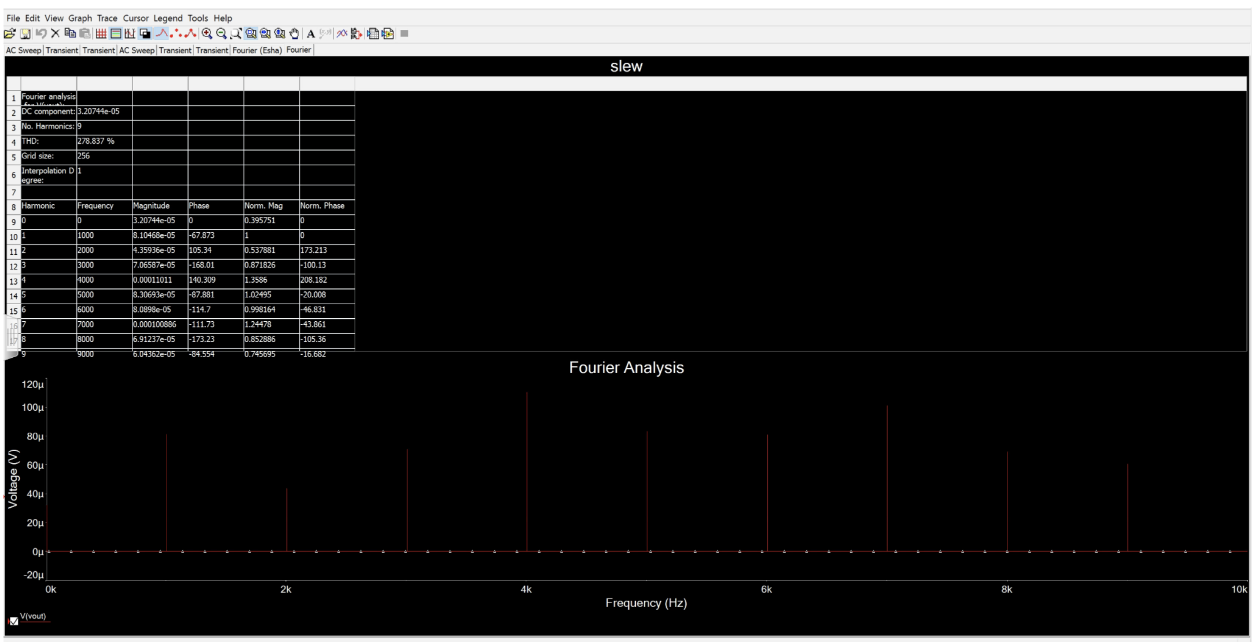
Fourier 75K 1V



Sin Transient 75K 2V

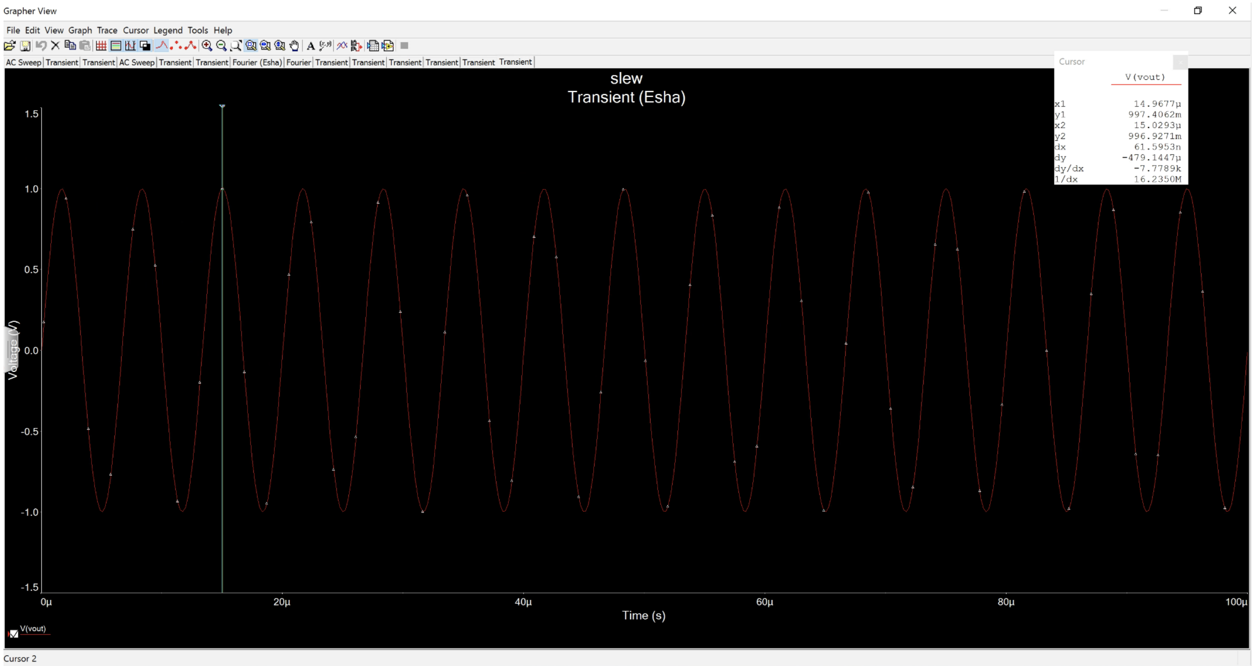


Fourier 75K 2V



1	Fourier analysis					
2	DC component:	3.20744e-05				
3	No. Harmonics:	9				
4	THD:	278.837 %				
5	Grid size:	256				
6	Interpolation Degree:	1				
7						
8	Harmonic	Frequency	Magnitude	Phase	Norm. Mag	Norm. Phase
9	0	0	3.20744e-05	0	0.395751	0
10	1	1000	8.10468e-05	-67.873	1	0
11	2	2000	4.35936e-05	105.34	0.537881	173.213
12	3	3000	7.06587e-05	-168.01	0.871826	-100.13
13	4	4000	0.00011011	140.309	1.3586	208.182
14	5	5000	8.30693e-05	-87.881	1.02495	-20.008
15	6	6000	8.0898e-05	-114.7	0.998164	-46.831
16	7	7000	0.000100886	-111.73	1.24478	-43.861
17	8	8000	6.91237e-05	-173.23	0.852886	-105.36
	9	9000	6.04362e-05	-84.554	0.745695	-16.682

Sin Transient 150K 1V



Fourier 150K 1V