Lab 12:
MOSFET Amplifier

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ECEN 325 Section 514

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Calculation

Choose $\hat{V_o} = 2.3V$, $R_i = 11k\Omega$

$I_X \geq \frac{2.3}{100} = 23mA \Rightarrow I_X = 40mA$

$I_{D2} = I_{D3} = I_X = 45mA$

$I_{D2} = \frac{\beta}{2} V_{ov}^2 \Rightarrow 45mA = \frac{95.464\ mA/V^2}{2} V_{ov2}^2$

$\Rightarrow V_{ov2} = 0.971V = V_{ov3}$

$g_{m2} = \beta V_{ov2} = 95.464 \cdot 0.971 = 92.69\ mA/V$

$A_{v2} = \frac{R_L}{\frac{1}{g_{m2}} + R_L} = \frac{100}{\frac{1}{92.69} + 100} = 1$

$\hat{V_d} = \frac{\hat{V_o}}{A_{v2}} = \frac{2.3}{1} = 2.3V$

Choose $V_{RX} = 0.55V$ $V_{RS} = 0.6V$

$V_{DD} + V_{SS} - \hat{V_d} - V_{RS} - V_{ov1} \geq V_{RD} \geq V_{RX} + V_{ov3} + \hat{V_o} + V_{tn} + V_{ov2}$

$5 + 5 - 2.3 - 0.55 - \frac{2V_{RD}}{50} \cdot 1 \geq V_{RD} \geq 0.6 + 0.971 + 2.3 + 2 + 0.971$

$6.875 \geq V_{RD} \geq 6.84 \Rightarrow V_{RD} = 6.875V$

$V_{ov1} = \frac{2 \cdot 6.875}{50} = 0.275V$

$I_{D1} = \frac{\beta}{2} V_{ov1}^2 = \frac{1.11}{2} \cdot 0.275^2 = 0.042mA = 42\mu A$

$R_D = \frac{V_{RD}}{I_{D1}} = \frac{6.875}{42\mu A} = 163.69k\Omega$ $R_X = \frac{0.55V}{45mA} = 12\Omega$

$R_S = \frac{0.6V}{45mA} = 13\Omega$

$V_{RG2} = V_{RS} + |V_t| + V_{OV} = 0.6V + 1.5 + 0.275 = 2.375V$

$$\begin{cases} V_{RG2} = 10 \cdot \dfrac{R_{G2}}{R_{G1}+R_{G2}} = 2.375V \\ R_i = 11K = \dfrac{R_{G1}\cdot R_{G2}}{R_{G1}+R_{G2}} \end{cases} \Rightarrow \underline{R_{G1} = 46315.8\Omega}, \underline{R_{G2} = 14426.2\Omega}$$

$$V_{RG4} = 0.55 + 2 + 0.971 = 3.521V$$

$$V_{RG4} = 3.521 = 10 \cdot \frac{R_{G4}}{R_{G3}+R_{G4}}$$

$$\Rightarrow \frac{352.1}{1000} = \frac{R_{G4}}{R_{G3}+R_{G4}} \Rightarrow \underline{R_{G4} = 352.1\Omega} \quad \underline{R_{G3} = 647.9\Omega}$$

I had the wrong value for Rs.

Rs should be $0.6V/ID_A = 0.6/42uA \approx 16k\Omega$

Simulation

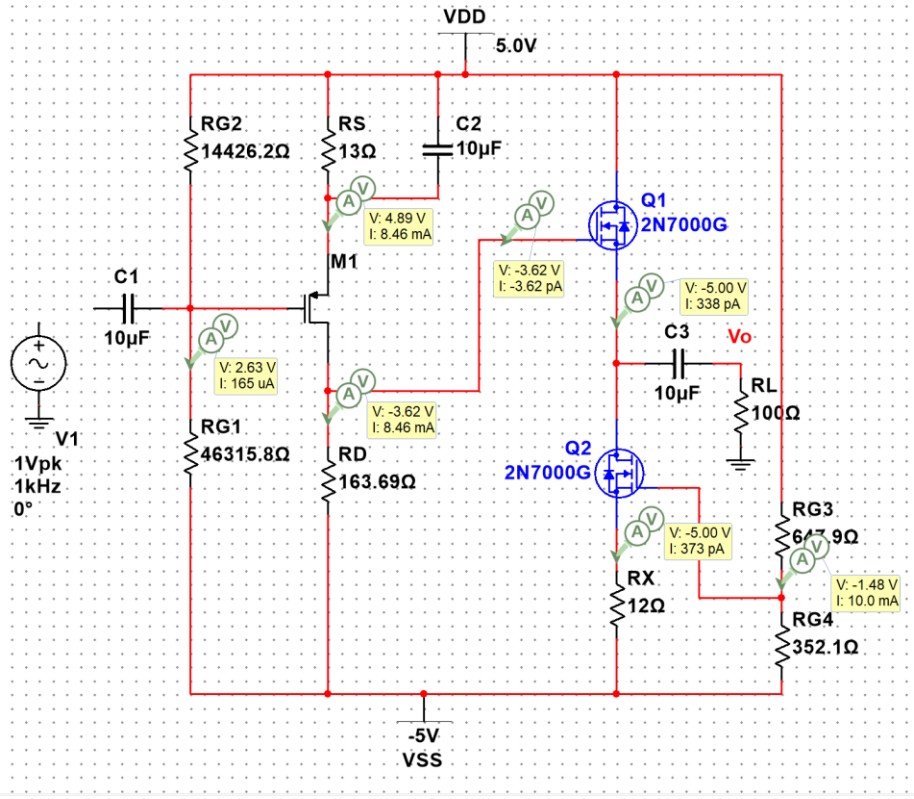

Figure 1: DC Solution for MOSFET amplifier ▲

V_{RG1} = 7.63V	V_{RS} = 0.11V	I_{D1} = 8.46mA
V_{RG2} = 2.37V	V_{RD} = 1.38V	I_{D2} = 338pA
V_{RG3} = 6.48V		I_{D3} = 373pA
V_{RG4} = 3.52V		

For this circuit, I got a gain of 0. I rework the circuit.

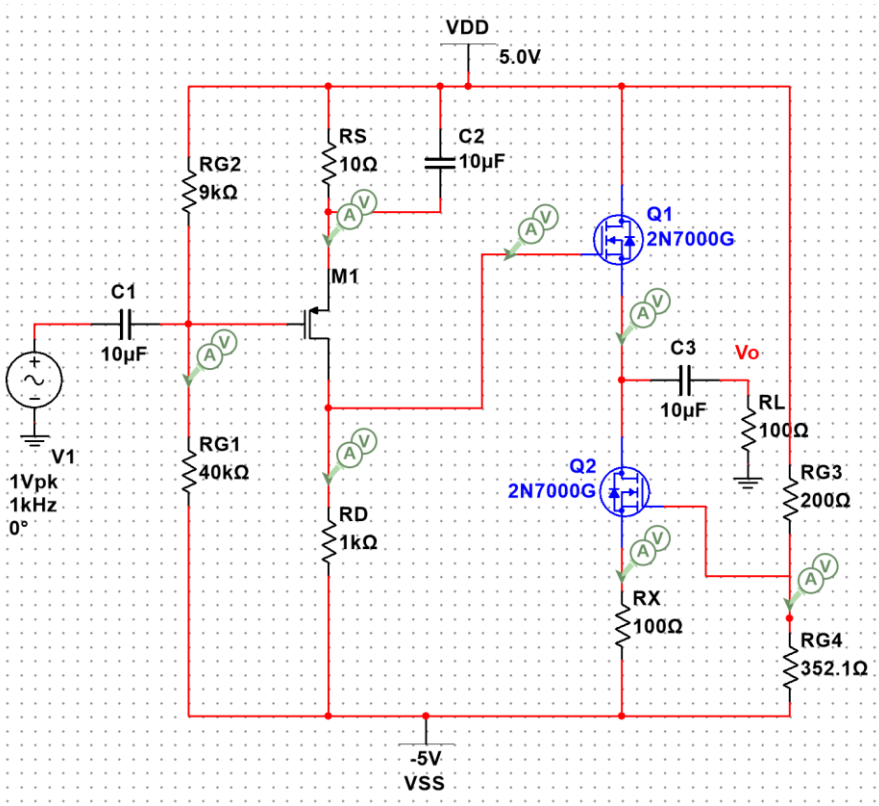

Figure 1.1: New circuit for MOSFET amplifier ▲

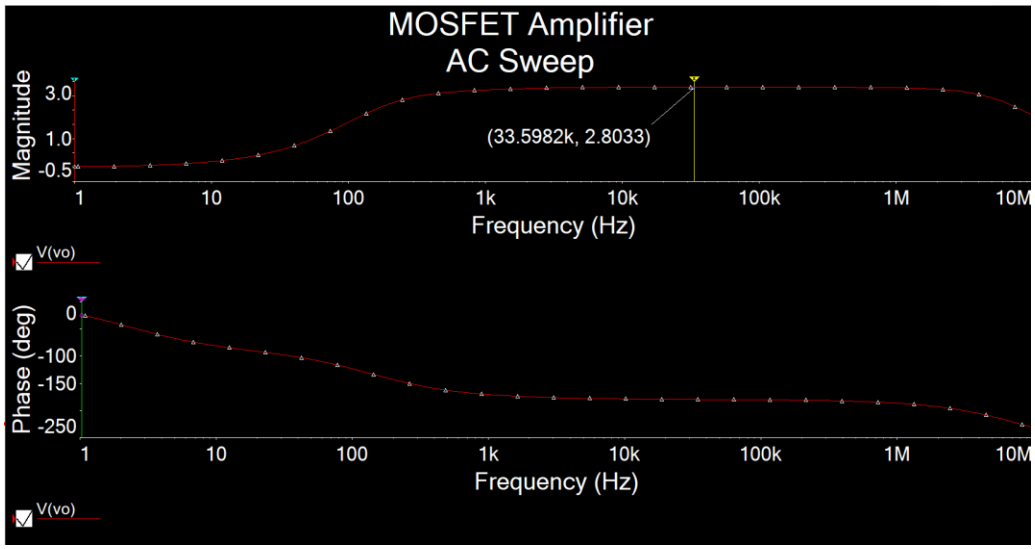

Figure 2.1: AC Simulation of A_V for MOSFET amplifier ▲

$A_V = 2.8033$

Even I rework the circuit, the best gain I can get is 2.8033.

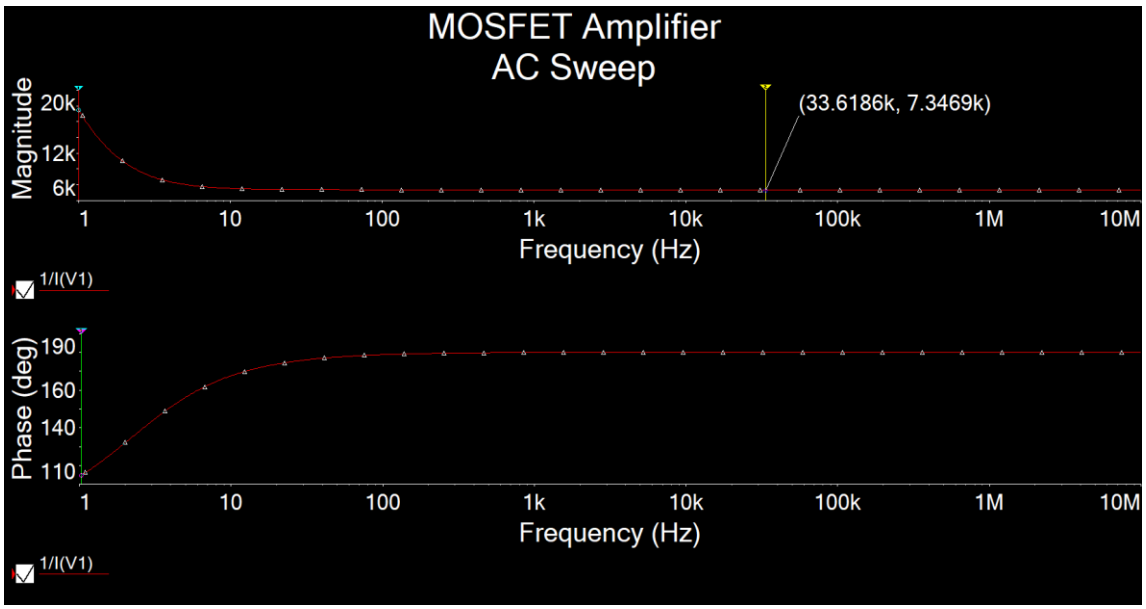

Figure 2.2: AC Simulation of R_i for MOSFET amplifier ▲

$R_i = 7.3469k\Omega$

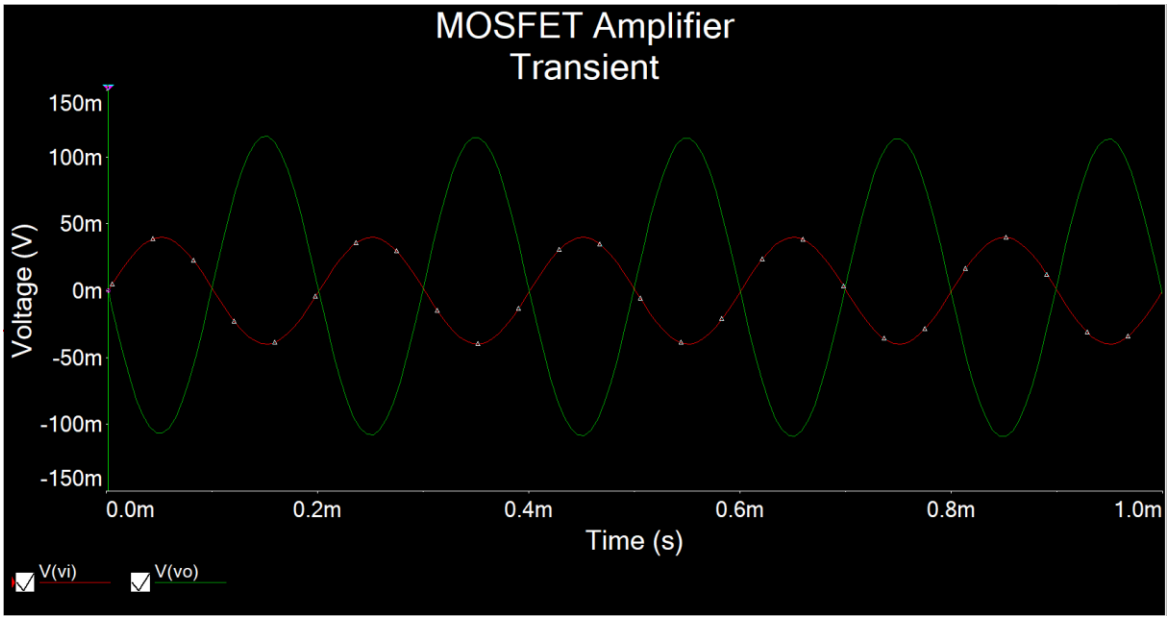

Figure 3: Time-domain waveform of V_i = 40mV 5kHz for MOSFET amplifier ▲

$A_V \approx 2$

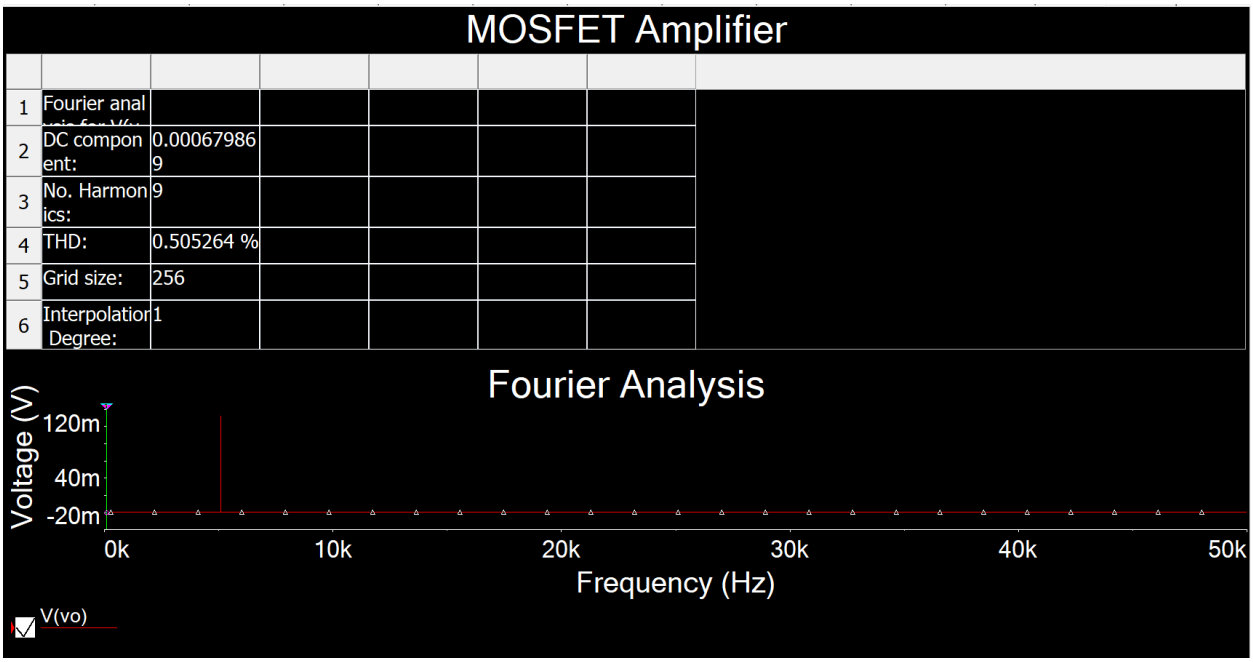

Figure 4: Total harmonic distortion (THD) for MOSFET amplifier ▲

THD = 0.5053%

New Simulation

I re-work the simulation using the values I got from lab measurement. However, I still couldn't get it to work.

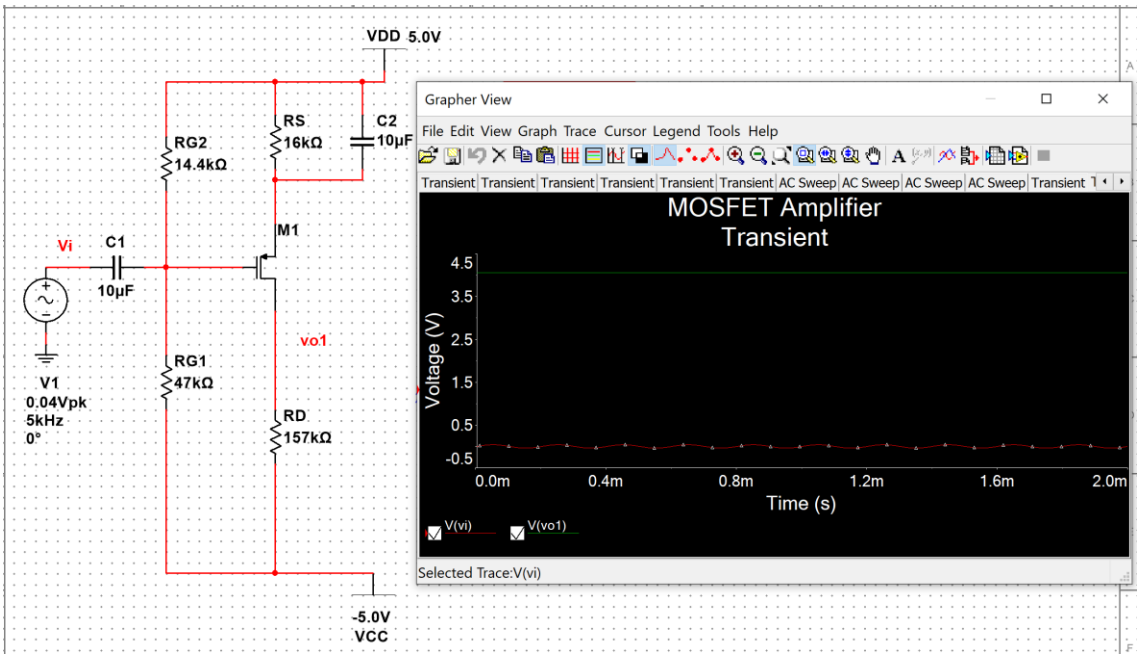

Figure 5.1: Time-domain waveform at **stage 1** of V_i = 40mV 5kHz for MOSFET amplifier ▲

$A_V \approx 0$

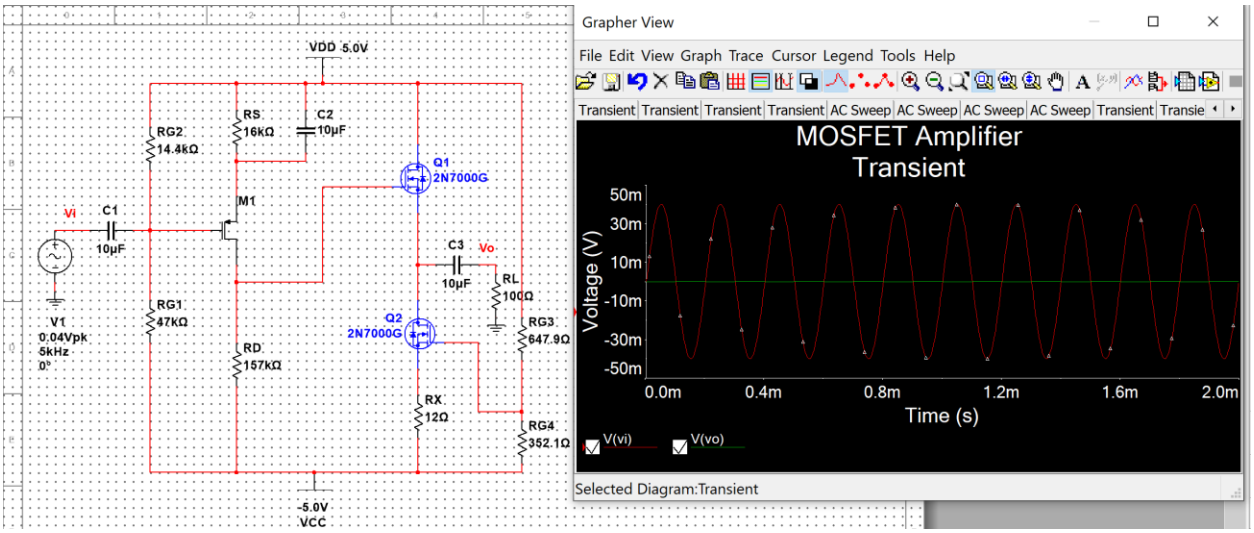

Figure 5.2: Time-domain waveform of V_i = 40mV 5kHz for MOSFET amplifier ▲

$A_V \approx 0$

Measurement

CD4007P	2N7000G	$R_D = 157k\Omega$	$R_{RG1} = 46k\Omega$
$\lambda = 0.0968$		$R_S = 16k\Omega$	$R_{RG2} = 14k\Omega$
$\beta = 1.11mA/V^2$	$\beta = 95.464mA/V^2$	$R_X = 12\Omega$	$R_{RG3} = 650\Omega$
$V_{Th} = 1.5V$	$V_{Th} = 2V$		$R_{RG4} = 350\Omega$

Table 1: Values used for MOSFET amplifier ▲

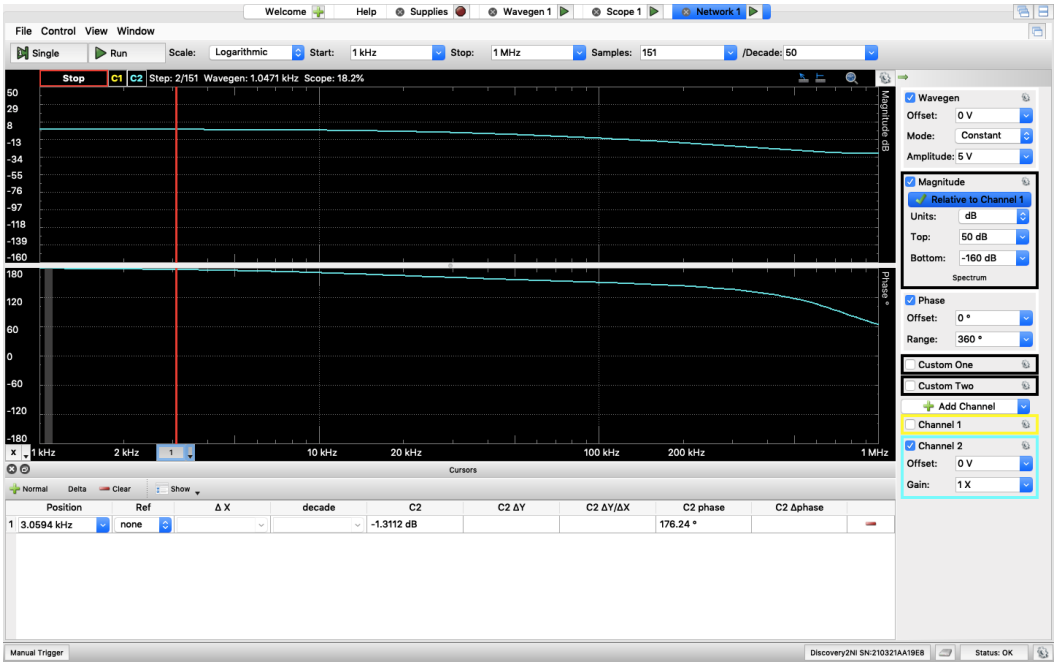

Figure 6.1: A_V for MOSFET amplifier ▲

$A_V = 10^{(-1.3112/20)} = 0.8599$

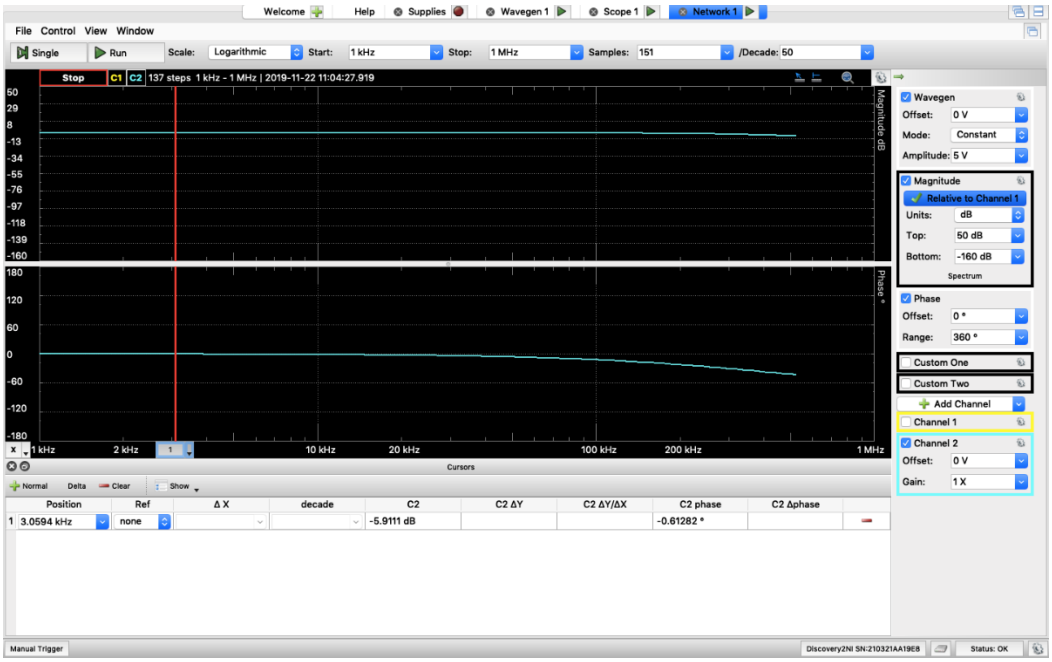

Figure 6.2: R_i for MOSFET amplifier ▲

$R_i / (11k + R_i) = 10^{(-5.911/20)}$

$R_i = 11.267k\Omega$

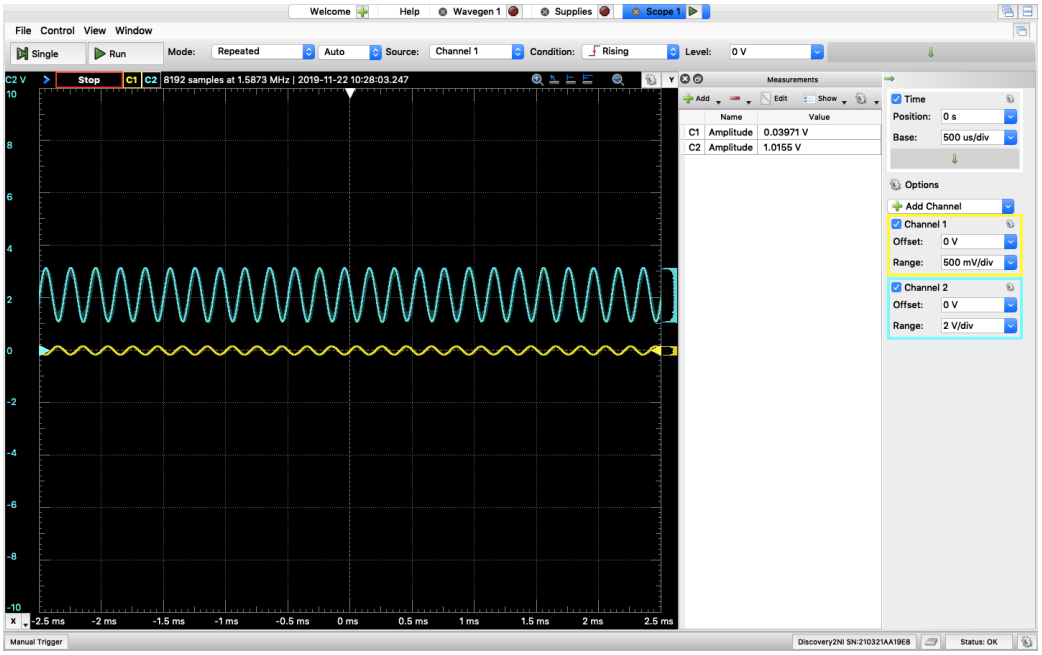

Figure : Time-domain waveform at **stage 1** of V_i = 40mV 5kHz for MOSFET amplifier ▲

$$A_V = \frac{1.0155}{0.03971} \approx 25.58$$

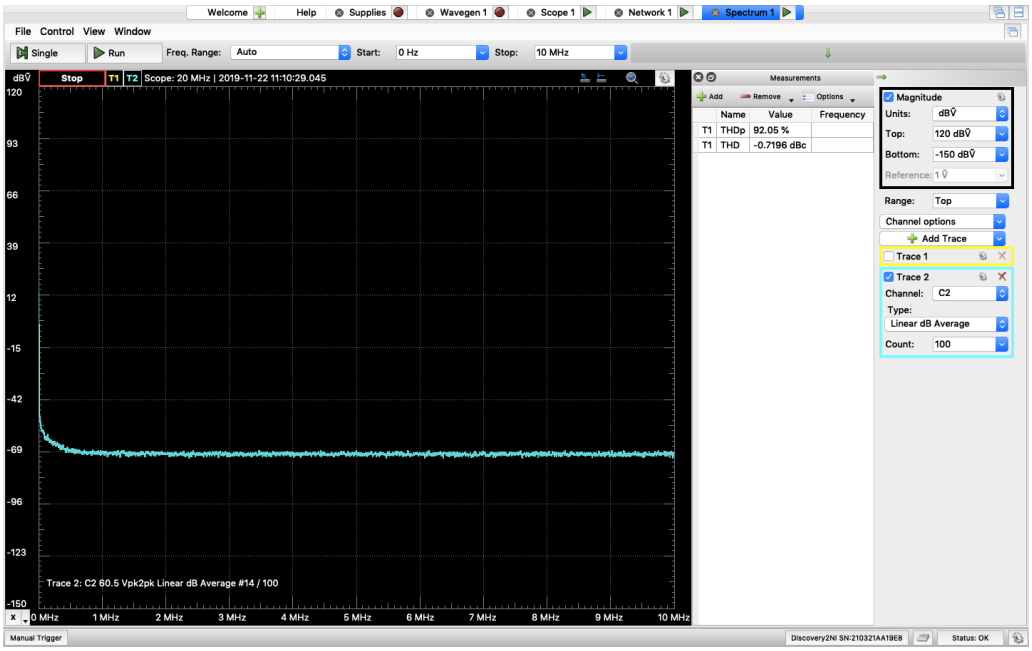

Figure 4: Total harmonic distortion (THD) at **Stage 1** for MOSFET amplifier ▲

THD = 92.05%

Table

Stage 1

	Calculation (without Lambda)	Calculation (without Lambda)	Simulation	Measurement
Gain	50	28	0	25.58
R_i	11kΩ	11kΩ	7.34kΩ	11.267kΩ

Calculation with λ =

$$r_o = \frac{1}{\lambda I_{D1}} = \frac{1}{0.0968 \cdot 42\mu A} = 245966$$

$$gain = \frac{r_o \| R_D}{R_D} \cdot Ideal\ gain$$

$$= \frac{r_o \| R_D}{R_D} \cdot 50 = 28.96$$

Comment

Lambda value (λ):

There is a lambda value (λ) in CD4007P that would affect the output gain. λ can be found using the characteristic circuit to find the early voltage (V_A), $\lambda = \frac{1}{V_A}$. This λ value would affect r_o and r_o would affect the gain. ($r_o = \frac{1}{\lambda * I_{D1}}$; $\frac{r_o || R_D}{R_D} * ideal\ gain = real\ gain$)

In my case, I got λ = 0.0968 and my R_D = 157kΩ and I_{D1} = 42uA. I used 50 as my ideal gain and calculated my real gain would be 28.96. In the measurement, I got a gain of 25.58 which is close to 28.96. In order for me to get a gain of 50 in measurement, I will need to use 89 as my ideal gain to calculate all the resistor values I need to use.

Measurement:

After I measured the stage 1 with a gain of 25, I connected it to stage 2. However, it didn't not work as expected to give me a gain of 25. It was much lower that 25. This might have the same reason as lab 10 where Analog Discovery 2 can only handle up to 250mW. To make circuit have a gain of 25, the circuit needs to be modified to reduce the power consumption at stage 1.