EE4C10 Analog Circuit Design Fundamentals

Homework Assignment IV

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Contents

Simulation Files

Each question with simulation files will have their respective subfolder.

Running the simulation files should be able to directly plot the graphs used (configured in the *.plt file). The folders for each question are arranged as follows after extracting:

```
spice
    q3
        a
        b
        c
        d
    q4
        a
        b
        c
```

Problem 1

(a) DC gain, $|\frac{V_{out}}{V_{in}}|$

KCL at drain node,

$$\frac{V_{out}}{R_D} = (g_m + g_{mb})v_s$$
$$\frac{V_{out}}{v_s} = (g_m + g_{mb})R_D$$

KCL at source node,

$$\frac{V_{in} - V_S}{R_S} = (g_m + g_{mb})v_s$$
$$\frac{V_{in}}{v_s} = R_S(g_m + g_{mb}) + 1$$

DC gain,

$$|\frac{V_{out}}{V_{in}}| = \frac{(g_m + g_{mb})R_D}{(g_m + g_{mb})R_S + 1}$$

(b) Pole of output node, $\omega_{p,out}$

$$R_{out} = R_D$$
$$C_{out} = C_{DB} + C_{GD}$$

$$\omega_{p,out} = \frac{1}{R_D(C_{DB} + C_{GD})}$$

(c) Input impedance,

$$Z_{IN} = \frac{1}{g_m + g_{mb} + s(C_{GS} + C_{SB})}$$

(d) Source capacitance, C_S, and input pole, $\omega_{p,in}$,

$$C_S = C_{GS} + C_{SB}$$

$$\begin{aligned}\omega_{p,in} &= \frac{g_m + g_{mb} + R_S^{-1}}{C_S} \\ &= \frac{g_m + g_{mb} + R_S^{-1}}{C_{GS} + C_{SB}}\end{aligned}$$

Problem 2

(a) Transfer function, $\frac{V_{out}(s)}{V_{in}(s)}$,
DC gain,

$$|\frac{V_{out}(S)}{V_{in}(s)}| = 1$$

Poles at gate and source nodes,

$$\omega_{p,G} = \frac{1}{R_S(C_{GB} + G_{GD})}$$

$$\omega_{p,D} = \frac{g_m}{C_{SB}}$$

Transfer function,

$$\begin{aligned}\frac{V_{out}(S)}{V_{in}(s)} &= \frac{1}{1 + sR_S(C_{GB} + G_{GD})} \frac{1}{1 + s\frac{C_{SB}}{g_m}} \\ &= \frac{1}{(1 + sR_S(C_{GB} + G_{GD}))(1 + \frac{sC_{SB}}{g_m})}\end{aligned}$$

(b) Poles at gate and source nodes,

$$\omega_{p,G} = \frac{1}{R_S(C_{GB} + G_{GD})}$$

$$\omega_{p,D} = \frac{g_m}{C_{SB}}$$

(c) Input impedance,

$$Z_{in} = \frac{1}{s(C_{GB} + C_{GD})}$$

Problem 3

(a) Testbench,

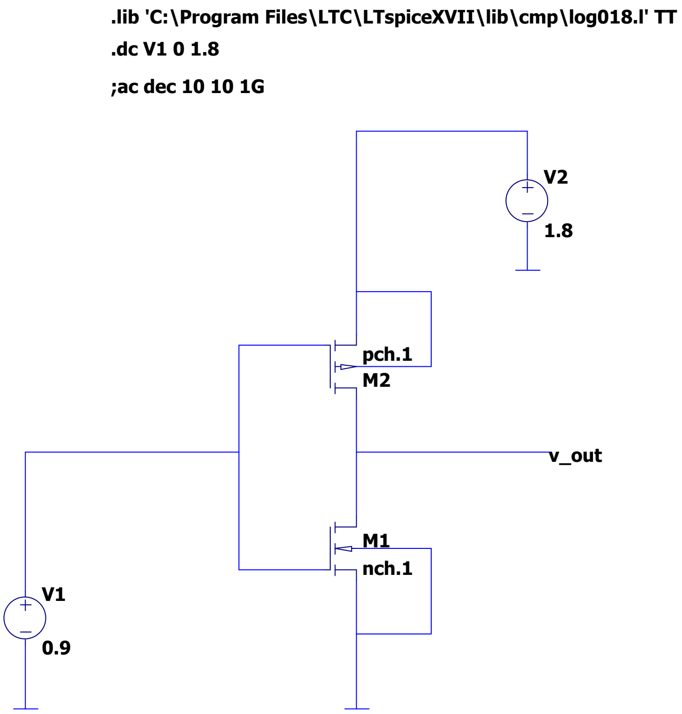

Figure 1: Inverter testbench

DC transfer curve,

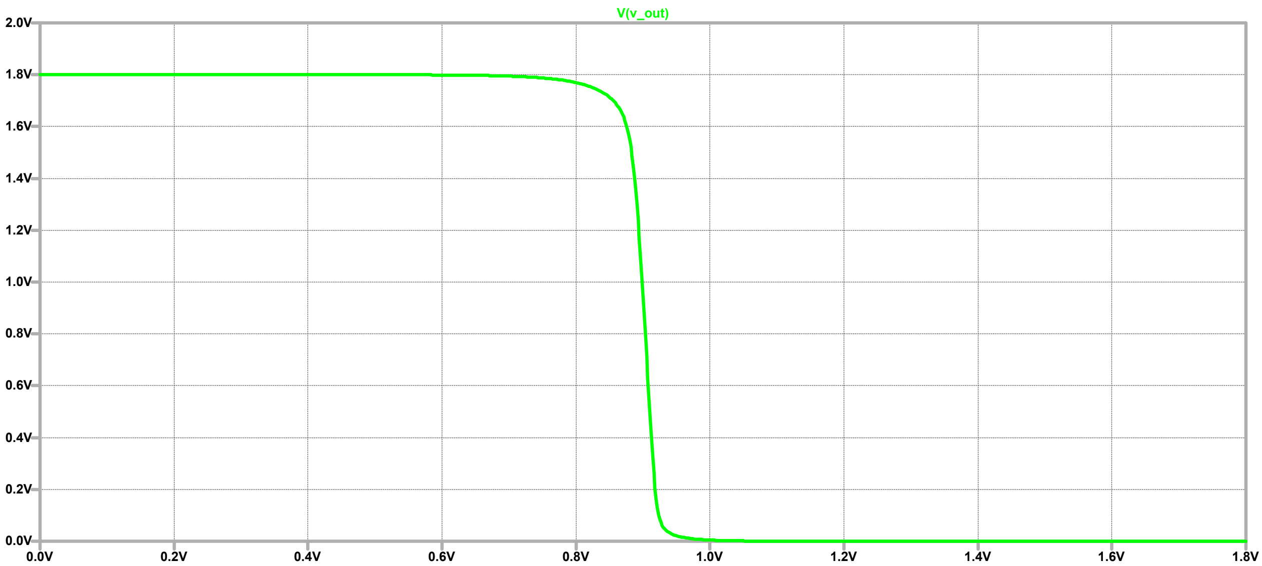

Figure 2: Inverter DC response

(b) Transient response,

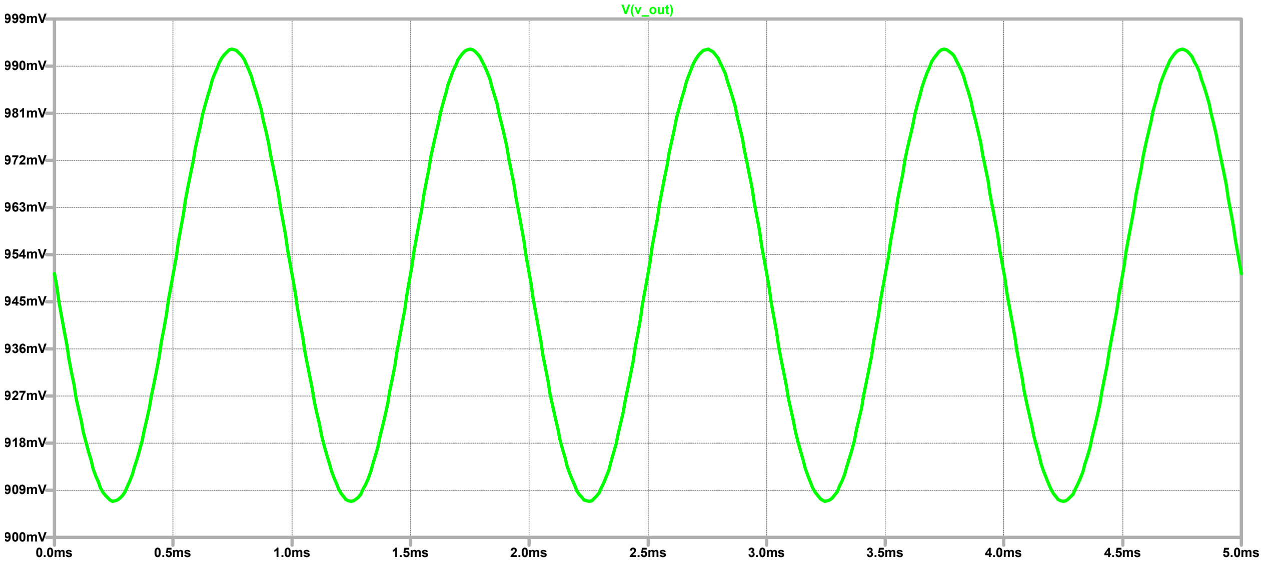

Figure 3: Inverter transient response

(c) AC responce

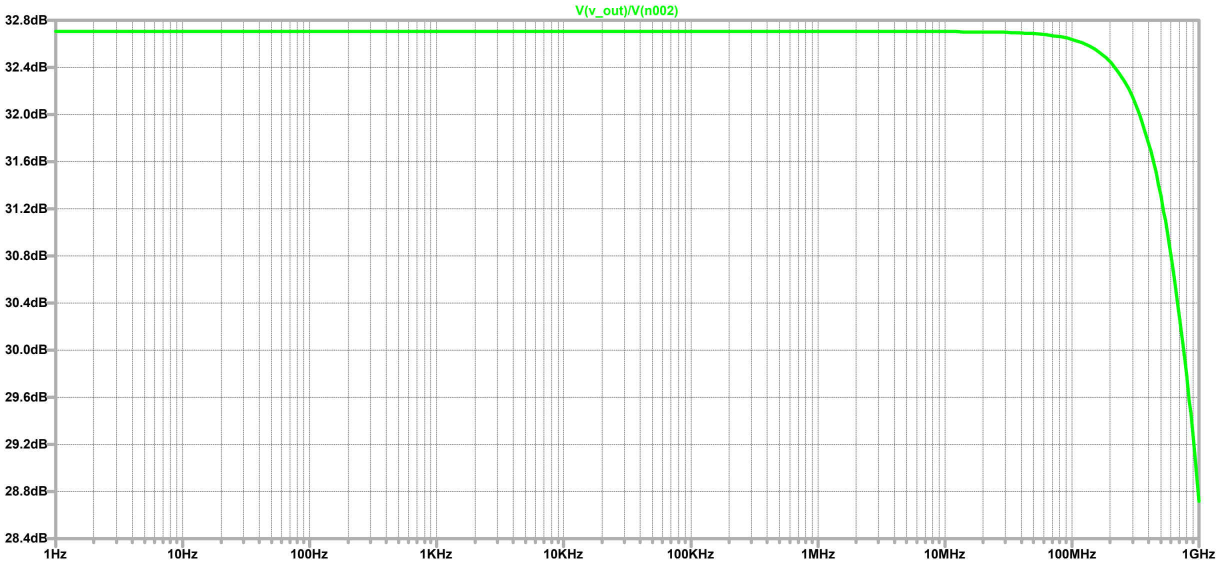

Figure 4: Inverter AC gain

$$
\begin{aligned}
|\frac{V_{out}}{V_{in}}| &= 32.7dB \\
&= 43.2 \\
\omega_p &= 2\pi f_{-3dB} \\
&= 5.136 \times 10^9 rads^{-1}
\end{aligned}
$$

(d) AC Response

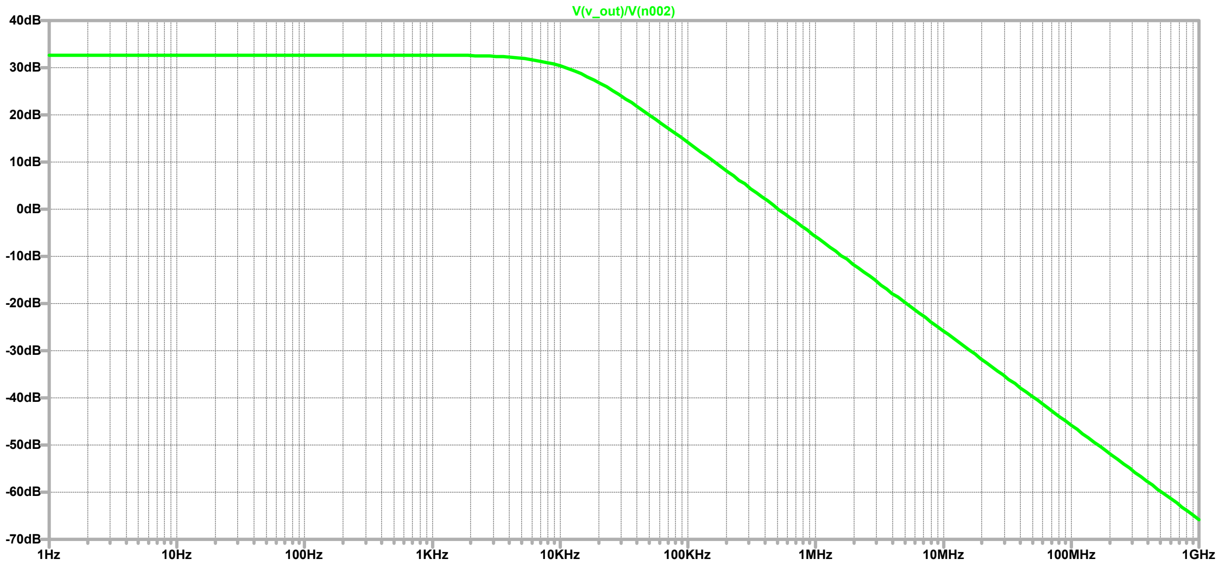

Figure 5: Inverter AC gain with output capacitor

$$\begin{aligned}
|\frac{V_{out}}{V_{in}}| &= 32.7dB \\
&= 43.2 \\
\omega_p &= 2\pi f_{-3dB} \\
&= 7.42 \times 10^4 rads^{-1}
\end{aligned}$$

(e) The pole at output node,

$$\begin{aligned}
RC &= \frac{1}{2\pi f_c} \\
R(C + \Delta C) &= \frac{1}{2\pi f_d}
\end{aligned}$$

$$\begin{aligned}
R &= \frac{1}{\Delta C}(\frac{1}{2\pi f_d} - \frac{1}{2\pi f_c}) \\
&= \frac{1}{\Delta C}(\frac{1}{2\pi f_d} - \frac{1}{2\pi f_c}) \\
R_{out} &= 134.75k\Omega
\end{aligned}$$

Problem 4

(a) Testbench

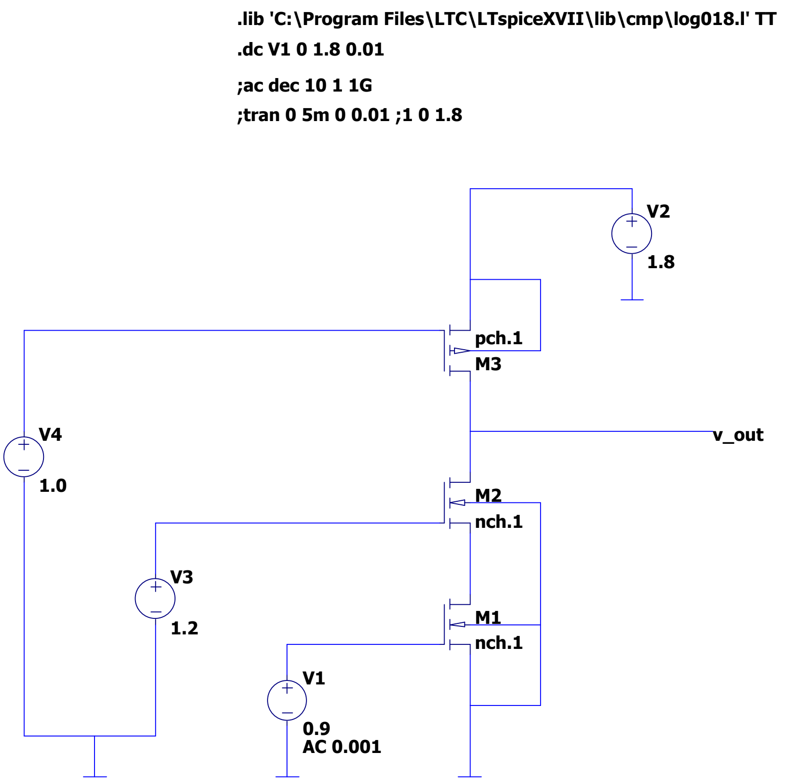

Figure 6: Testbench

DC transfer curve,

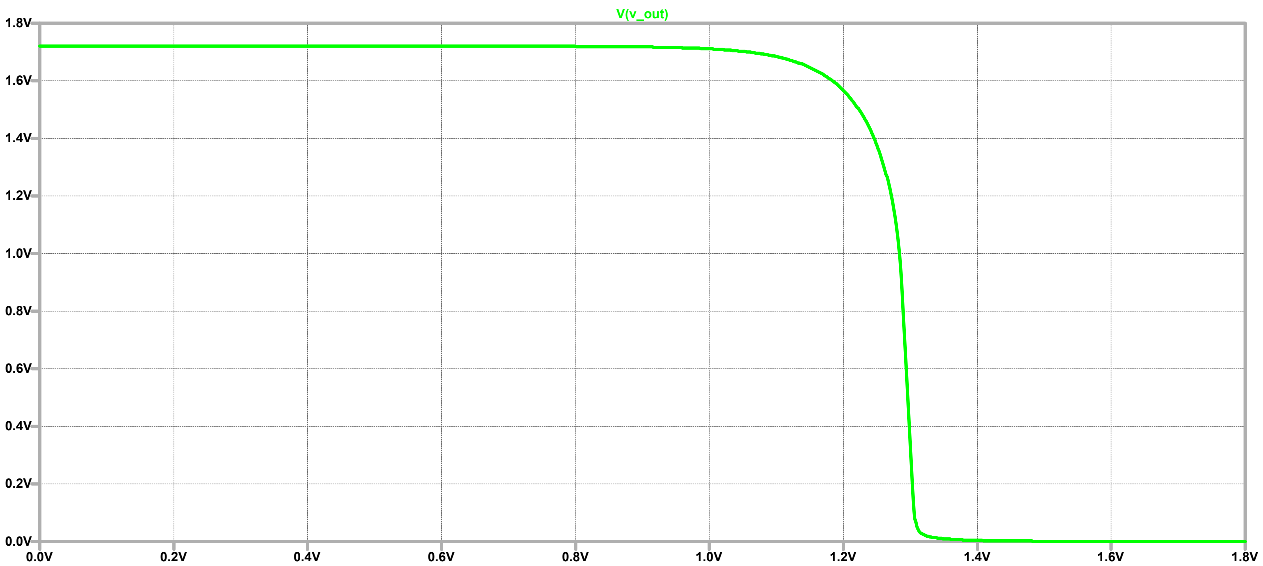

Figure 7: DC response

(b) Transient response,

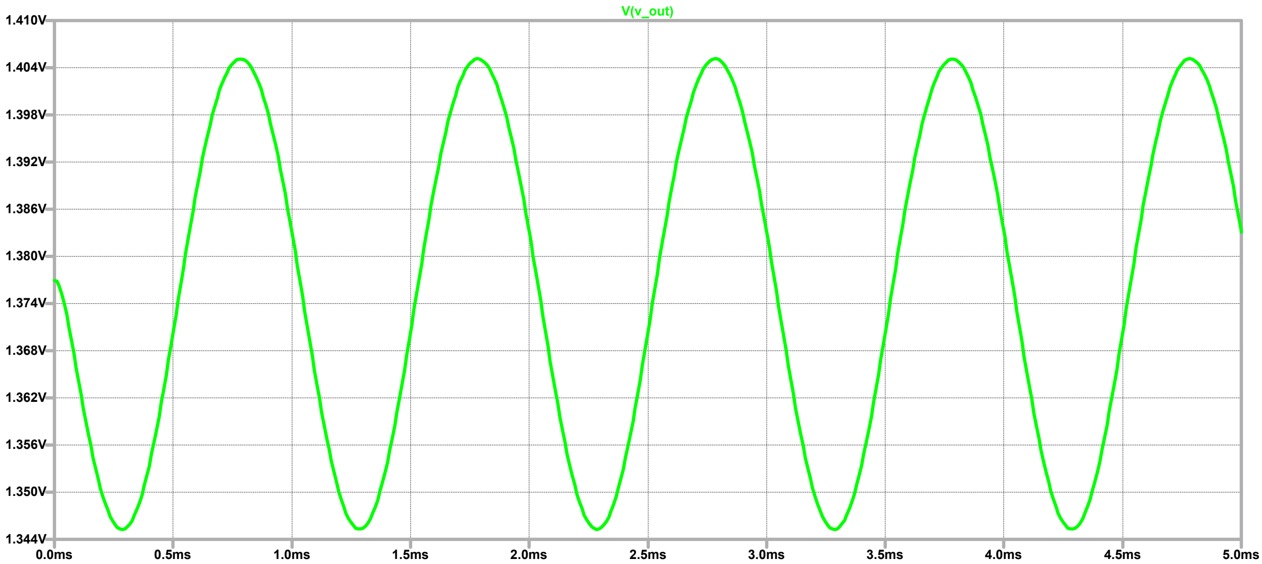

Figure 8: Transient response

(c) AC response

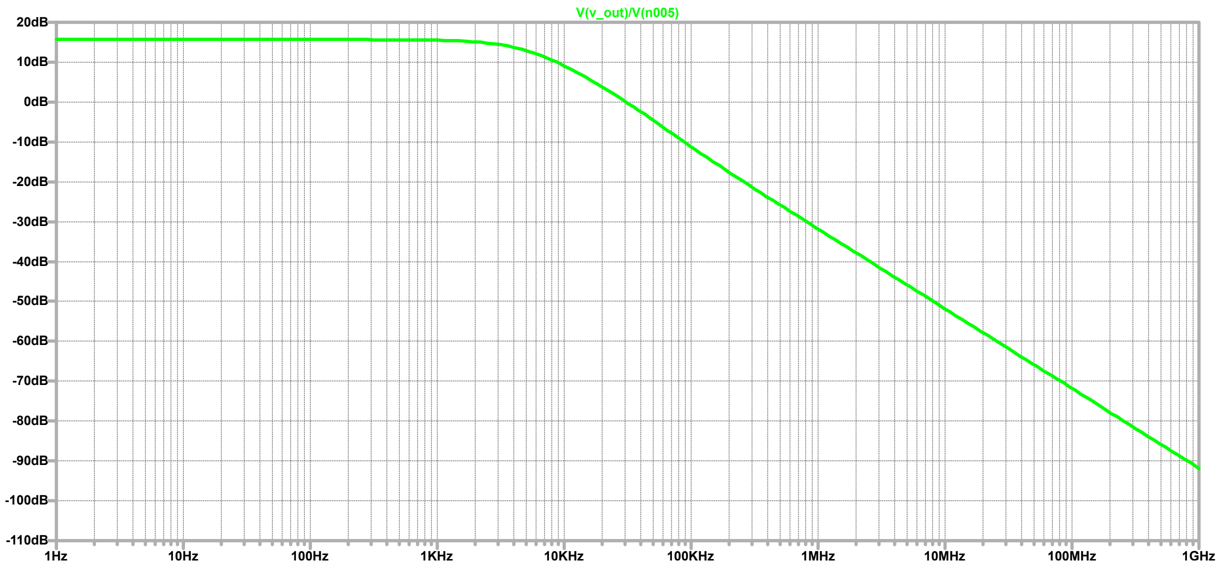

Figure 9: Inverter AC gain

$$
\begin{aligned}
|\frac{V_{out}}{V_{in}}| &= 15.7dB \\
&= 6.06 \\
\omega_p &= 2\pi f_{-3dB} \\
&= 3.35 \times 10^4 rads^{-1}
\end{aligned}
$$

(d) Gain bandwidth product, GBWP

$$
\begin{aligned}
|\frac{V_{out}}{V_{in}}| &= 6.06 \\
f_{-3dB} &= 5.331kHz
\end{aligned}
$$

$$GBWP = 32.3kHz$$