Problem 1

Consider the CMOS inverter pictured below. Take channel length modulation into account.

\[ VDD=1.5V \]

\[ W/L=12/1.5 \]

\[ W/L=6/1.5 \]

\[ C_{load}=0.5pF \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NMOS</th>
<th>PMOS</th>
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</thead>
<tbody>
<tr>
<td>( V_{TO} )</td>
<td>0.5 V</td>
<td>-0.5 V</td>
</tr>
<tr>
<td>( \mu )</td>
<td>220 cm(^2)/Vs</td>
<td>110 cm(^2)/Vs</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>0.1 V(^{-1})</td>
<td>0.1 V(^{-1})</td>
</tr>
<tr>
<td>( T_{ox} )</td>
<td>15 nm</td>
<td>15 nm</td>
</tr>
</tbody>
</table>

- **Dimensions of W and L are in \( \mu m \)**
  
  a) Calculate \( V_M \), the voltage midpoint.
  b) Calculate \( A_V \), the voltage gain at \( V_{in}=V_M \).
  c) Calculate \( N_{ML} \) and \( N_{MH} \), the noise margin low and noise margin high.
  d) Calculate \( t_{PHL} \) and \( t_{PLH} \), the propagation delay from high-to-low and propagation delay from low-to-high.
Problem 2

We will now use the following SPICE model and compare our hand calculations from Problem 1 with simulated results.

```
.MODEL N15 NMOS LEVEL=1 VT0=0.5 TOX=1.5e-8 U0=220 LAMBDA=1.0e-1
+GAMMA=0.6 CJ=1e-4 CJSW=5e-10 PB=0.95
.MODEL P15 PMOS LEVEL=1 VT0=-0.5 TOX=1.5e-8 U0=110 LAMBDA=1.0e-1
+GAMMA=0.6 CJ=3e-4 CJSW=3.5e-10 PB=0.9
```

a) Use the DC sweep on the input voltage to simulate transfer characteristics using SPICE. Compare VM, AV, NML, NMH, with the calculated results.
b) Use the Pulse input to simulate an input waveform shown below using SPICE. Compare tPHL and tPLH with your hand calculations.

![Input Waveform](image)

Problem 3

Consider the circuit below, which consists of an NMOS device and resistor load. Disregard channel length modulation for this problem.

a) Calculate VM, VOH, VOL. Remember, for hand calculations we assume VOH=VMAX, and VOL=VMIN.
b) Calculate the voltage gain of this circuit, when Vin=VM.
Problem 4

Consider the circuit below, which consists of an NMOS device and PMOS current source load. Do not neglect channel length modulation.

a) Calculate the width of the PMOS device so its saturation current is 50µA.

b) Calculate $V_{\text{M}}$, $V_{\text{OH}}$, $V_{\text{OL}}$. Remember, for hand calculations we assume $V_{\text{OH}}=V_{\text{MAX}}$, and $V_{\text{OL}}=V_{\text{MIN}}$.

c) Calculate the voltage gain of this circuit, when $V_{\text{in}}=V_{\text{M}}$. 