Question 1 [15 marks]:

a) Conventionally we use positive voltages to represent logic signals (low = 0V and high = +5V for example). Draw a diagram for a complementary inverter (i.e. an inverter comprising of separate p-type and n-type transistors) that works with negative voltages (e.g. low = 0V and high = -5V) and a negative supply voltage. Explain why this device would operate as expected. [3 marks]

b) A complementary inverter is fabricated that has an infinite gain (i.e. perfectly sharp switching characteristics) at a switching voltage of $V_{in} = 3$V. If the inverter has the following voltage truth table, determine the low noise margin and high noise margin of this inverter. [3 marks]

<table>
<thead>
<tr>
<th>$V_{in}$</th>
<th>$V_{out}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0V to 3V</td>
<td>0.5V</td>
</tr>
<tr>
<td>3V to 5V</td>
<td>4V</td>
</tr>
</tbody>
</table>

c) Figure 1 shows the output voltage as a function of input voltage for a highly-optimized complementary inverter. This data is available to download here with input voltage step sizes of 100mV and here with input voltage step sizes of 10mV. Determine the gain for this inverter from both sets of data, and use the result as an example to explain why care should be taken when measuring inverters to report gain. [5 marks]

![Figure 1](image.png)

**Figure 1** Output voltage as a function of input voltage for complementary inverter. This data is available to download here with an input voltage step size of 100mV and here with an input voltage step size of 10mV.

d) State one positive aspect of using ambipolar TFTs in inverters for thin film electronics. [1 mark]

e) State one negative aspect of using ambipolar TFTs in inverters for thin film electronics. [1 mark]

f) Figure 2 below shows a circuit made from p-type and n-type TFTs. Assuming the static noise margins are high in this circuit, sketch the output voltage as a function of time, with a positive supply voltage. The qualitative form of the output is important, not the absolute numbers. [2 marks]
Question 1 [5 marks]:
   a) Provide an example of a printable electronic device that could conceivably require non-volatile memory onboard. [1 mark]
   b) Provide a reason why it might be challenging to replicate flash memory using thin film electronics. [1 mark]
   c) Explain briefly why it is desirable in three terminal memory devices for memory states to be defined by modifying the threshold voltage, as opposed to say changing the average mobility. [1 mark]
   d) Briefly explain why you would expect redox based memory devices to have long write and erase times. [1 mark]
   e) Briefly explain why you would expect filamentary conduction to have a long retention time. [1 mark]

Figure 2 Circuit made from a combination of p-type and n-type TFTs.