

**ESE 3700 Lab 1: Gates From Discrete Transistors**  
**January 23<sup>th</sup>, 2023**

**(updated August, 2017, based on original writeup by Andrew Townley)**

In this lab, you will be constructing a NAND2 gate from discrete transistors. The transistor models you will be using are:

- ZVN3306A (NMOS);  
<http://www.seas.upenn.edu/~ese3700/spring2022/handouts/ZVN3306A.pdf>
- ZVP3306A (PMOS);  
<http://www.seas.upenn.edu/~ese3700/spring2022/handouts/ZVP3306A.pdf>

**IMPORTANT:** Technically, the source and drain of typical MOSFETs are interchangeable, at least in the IC domain. Discrete MOSFETs have ESD protection diodes to help prevent the device from being destroyed by static electricity buildup; these ESD devices make it safer for you to touch the device. The side effect of this is that the source and drain of the devices we will use in the lab are no longer interchangeable. Figure 1 depicts the pin connections of the transistor terminals; you can identify the pins by distinguishing between the flat and curved sides of the transistor package.

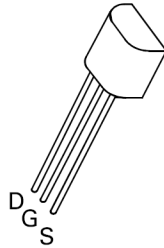
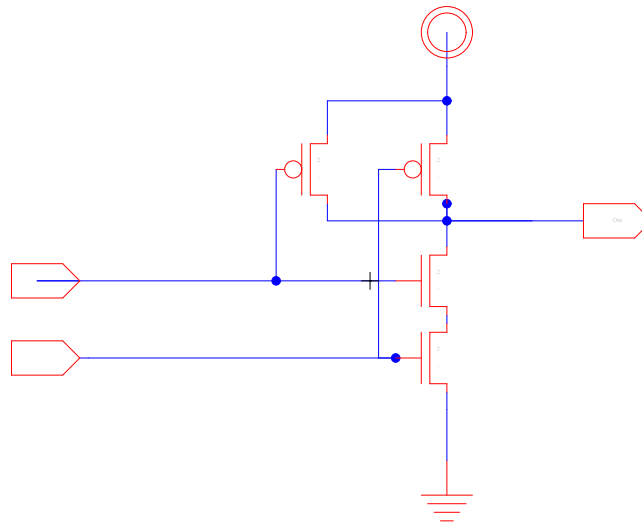


Fig. 1: Drain, Gate, and Source terminals of the ZVN3306A & ZVP3306A

**Work in a group of 2** to wire up a NAND2 gate with the schematic shown here:  
**Again, be careful with the orientation of the transistors!**



When wiring up the NAND2 gate, be sure that the source and drain terminals are connected properly. Remember the sources should be closest to the respective supply. Labeling the above schematic with D/S will be a helpful exercise.

The supply voltage  $V_{DD}$  should be set to 4 V. This voltage should be supplied from the bread board station. Use the multimeter to measure and set the power supply for accuracy. Here is a video on how to use the multimeter to make DC measurements:  
[https://www.youtube.com/watch?v=Or-M7\\_bCZbk&t=183s](https://www.youtube.com/watch?v=Or-M7_bCZbk&t=183s)

### **Verify Logical Operation:**

Verify that your wired gate performs the NAND function by directly connecting your inputs to GND (0) and VDD (1) and using the multimeter to measure the output. You should test the whole truth table to verify functionality **before you move on to the next step.**

### **Function Generator:**

Set up the function generator to drive a 1 MHz square wave with offset 2 V, and amplitude 4 V (peak-to-peak). Ensure that the function generator is in High-Z mode. You may need to re-adjust the offset and peak-to-peak voltages after switching to High-Z mode. Use the oscilloscope to verify your waveform is outputted correctly.

#### *NOTES for High-Z mode:*

For the HP function generator: to set the output termination to High-Z, press Shift+Enter, then press right until you reach Sys Menu, down once to Out Term, down again, press right or left once to change the value to High-Z, then Enter to exit the menu).

For the Agilent function generator: Press Channel→output load→set to High-Z.

### **Verify Switching Operation:**

Connect one input to VDD and the other input to the output of the function generator. Display both the input and output of your gate on the scope. See that the output switches as you expect. Switch the static input to GND and similarly verify expected operation.

### **DC Transfer Function:**

Connect the static input back to VDD. Set up the function generator to produce a 1 kHz ramp waveform (button next to the green “4” label). Ensure that the function generator is still in High-Z mode, and set the input signal amplitude to 4 V and the offset to 2 V.

Plot your gate output on the scope, along with the input ramp signal. Save an image of these waveforms using the using a USB flash drive on the scope or the Intuilink software.

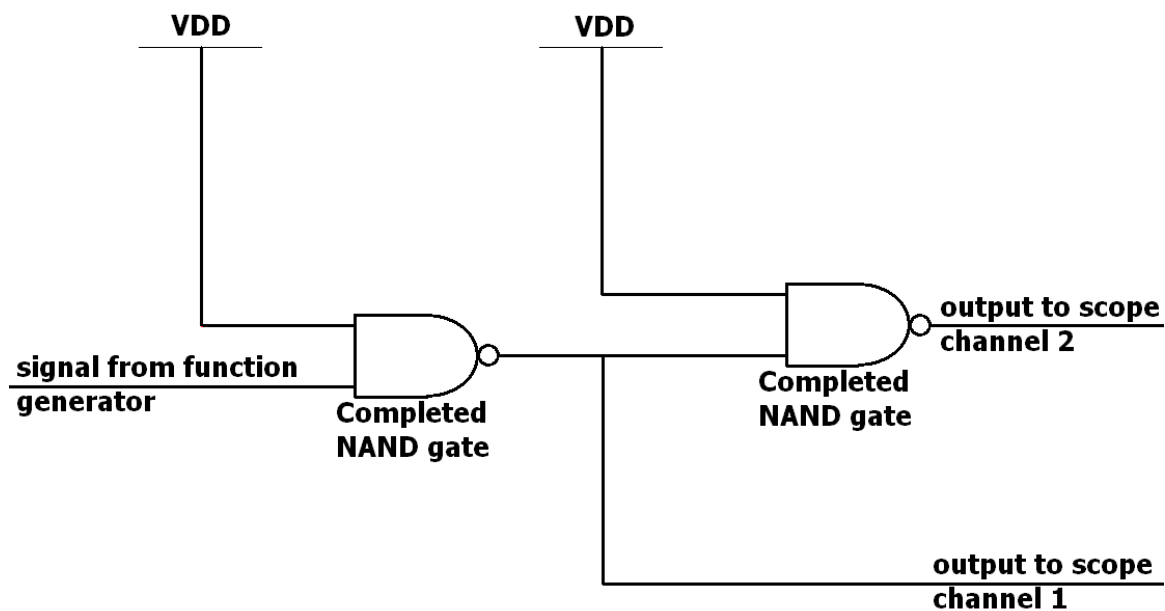
Video instructions for capturing an image and data are here:

<https://www.youtube.com/watch?v=YoXMoZSuXpU&feature=youtu.be>

You should also save out the  $V_{in}$  and  $V_{out}$  data points (use “capture waveform”). See HW 1 question 5 for more information.

### Transient waveform capture:

Once you have constructed and tested your gate, you should wire up another NAND gate and cascade them together to build the test setup shown in Figure 2. Verify functionality of the second gate the same way you did the first before you cascade them together!



**Figure 2: Test setup for NAND gate**

Set your input signal back to a square wave. Capture an image (and waveform data) for all three signals displayed on the scope using Intuilink or USB flash drive.

With this setup you should measure the propagation delay and rise time of your gate when driving a transistor gate load similar to your gate. You should capture images and data from the input and output switching waveforms. See HW 1 question 5 for more information.

**Make sure you have all the data you need for HW1 before you leave lab.**

**Tips:**

In my experience, these scopes seem to track square-wave signals better when negative slope triggering is used. (Auto-Scale, then press Slope | Coupling button, then press leftmost scope display button to toggle the triggering slope from positive to negative).