BEE 271 Digital circuits and systems
Summer 2016
Lab 1: Digital logic devices

1 Objectives

The purpose of this lab is to familiarize you with the characteristics of some simple TTL parts that implement basic digital logic functions and with the use of our lab instruments.

There are no previous core EE course requirements for this class, so it's perfectly okay if you've never used the lab instruments before and need help.

2 Transistor-transistor logic

Transistor-transistor logic (TTL) is a type of digital circuitry built using bipolar junction transistors (BJTs) and resistors. It's called transistor-transistor logic because both the logic function applied against the input and the amplification needed to drive the output are done with transistors, in contrast to earlier RTL and DTL technologies that used resistors or diodes to perform the logic function.

The most popular family of TTL components is the SN7400 series of small-scale integration (SSI) parts introduced by Texas Instruments in 1964, starting with the SN7400 quad 2-input NAND, originally in a metal package for the military, and in 1966, in a plastic DIP for commercial customers. There are now over 600 different parts in the SN7400 series and several variations on the internal circuitry offering a choice of speed and power trade-offs.

As shown in figure 1, the first stage in a TTL NAND gate is a non-inverting common base amplifier but with a transistor that's been fabricated with multiple emitters in the base, allowing it to be controlled by multiple inputs, thus performing the logic function. The second stage is a common emitter that provides the inverting amplification.

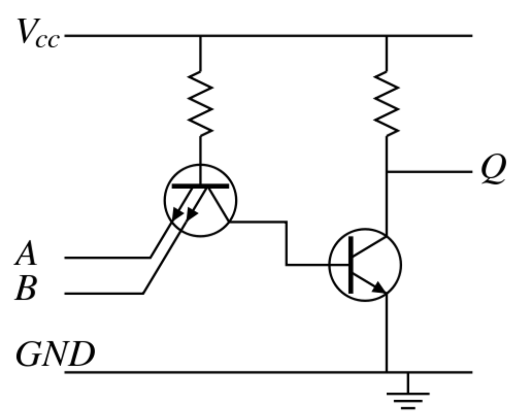

Figure 1. A simplified TTL NAND gate.
https://en.wikipedia.org/wiki/Transistor-transistor_logic

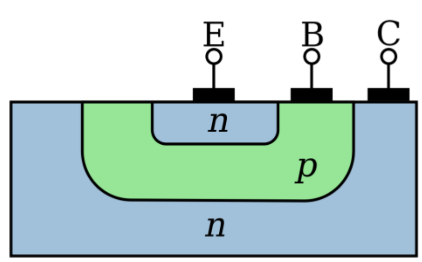

Figure 2. NPN BJT cross-section.
https://en.wikipedia.org/wiki/Bipolar_junction_transistor

TTL was especially popular in the 1970s and 1980s for prototyping and debugging designs intended for fabrication as integrated circuits. By using hundreds or even thousands of

7400 parts on big wire-wrap boards, a node-for-node model of a proposed chip could be built that would run at full speed, important in debugging something that had to respond to realtime input, and allow the designer to put a logic probe on a TTL pin to examine a signal that would be buried inside the final chip.

Figure 3 shows the TTL voltage levels for high and low states. Notice there is a 0.4 V noise margin between the allowable input and output values.

Today, simulation software and field programmable gate arrays (FPGAs) have replaced TTL SSI for prototyping but the parts remain popular for boardboarding and as system “glue”, parts there on a board simply to connect the main components together.

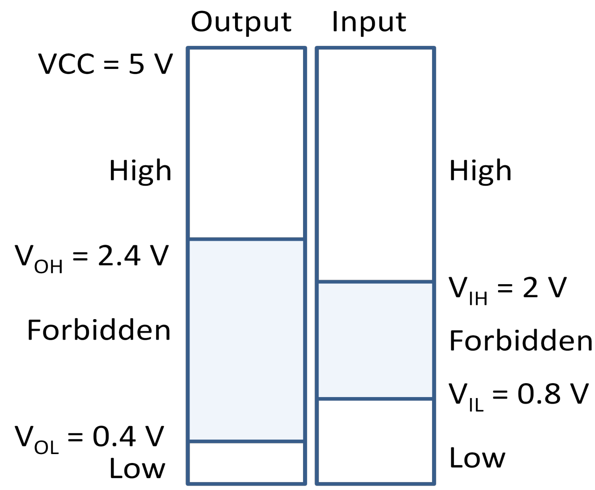

Figure 3. TTL voltage levels.

3 Parts

Here are the parts you’ll examine.

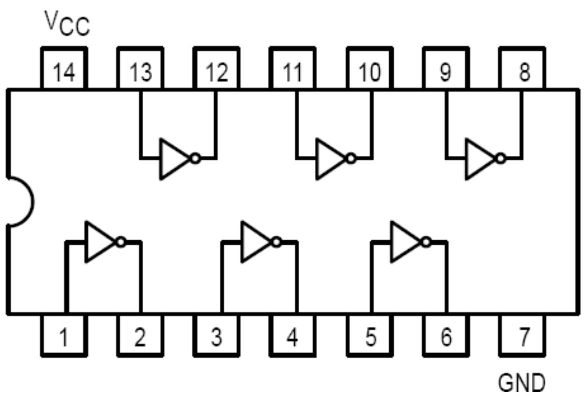

Figure 4. 7404 Hex inverter.

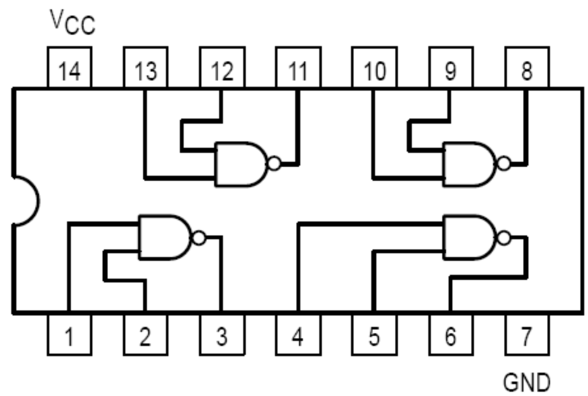

Figure 5. 7400 Quad 2-input NAND gate.

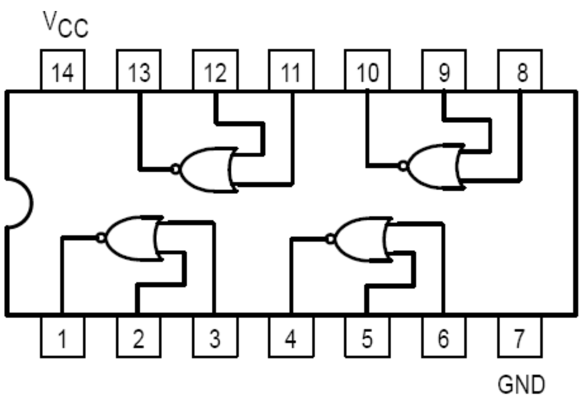

Figure 6. 7402 Quad 2-input NOR gate.

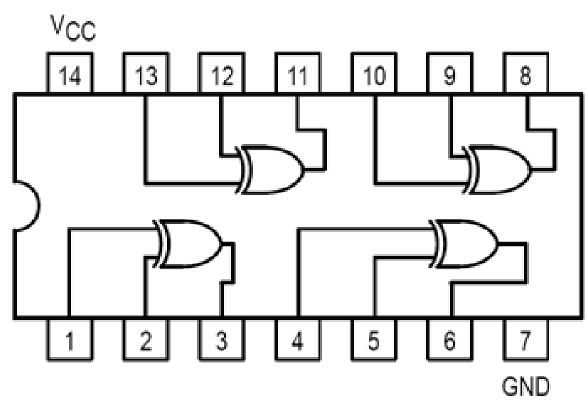

Figure 7. 7486 Quad 2-input XOR gate.

4 Boolean functions

4.1 7400 NAND gate

Build the circuit in figure 8 with red LEDs and 470 Ω resistors.

Construct a truth table shown in figure 9 for the NAND gate by trying all 4 possibilities of the inputs A and B tied high to 5 V = 1 or low to ground = 0 and observing the LEDs.

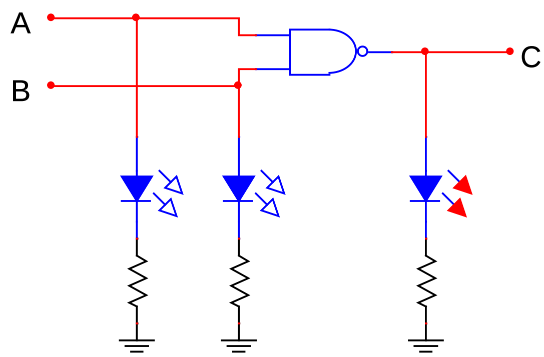

Figure 8. Testing NAND gate Boolean functions.

4.2 7402 NOR gate

Rewire your circuit with a 7402 NOR gate in place of the NAND and construct a truth table for this function by varying the inputs and observing the LEDs.

A	B	C
0	0	
0	1	?
1	0	
1	1	

Figure 9. A truth table.

4.3 7486 XOR gate

Rewire your circuit with a 7486 XOR gate in place of the NOR and construct a truth table for this function by varying the inputs and observing the LEDs.

4.4 Latch

Build the circuit in figure 10 using two NAND gates, two 10K resistors, two LEDs and two 470 Ω resistors. Alternate briefly shorting the S* input to ground, then briefly shorting the R* input to ground. Repeat this several times until you discover what this circuit does.

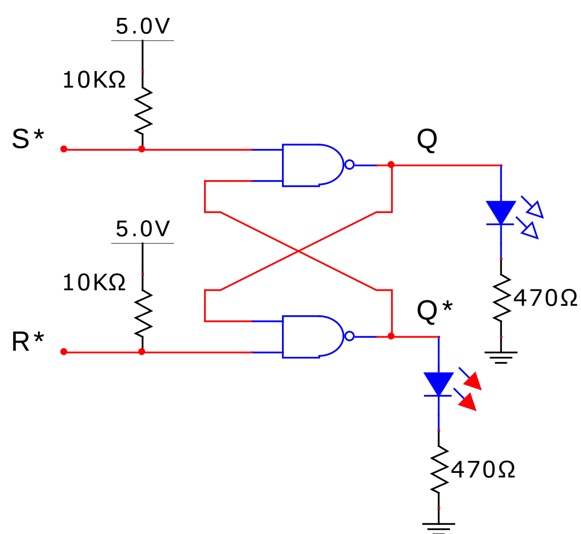

Figure 10. Latch.

4.5 Active low versus active high

Build the two circuits shown in figure 11 side-by-side using two NAND gates and two 470 Ω resistors. Both LEDs should light up. Record the measured values of your resistors, the power supply voltage and the voltages at A and B.

The circuit on the left is called active high because the LED turns on (activates) when the output from the NAND is high = 1. The one on the right is called active low because the LED turns on when the output is low = 0.

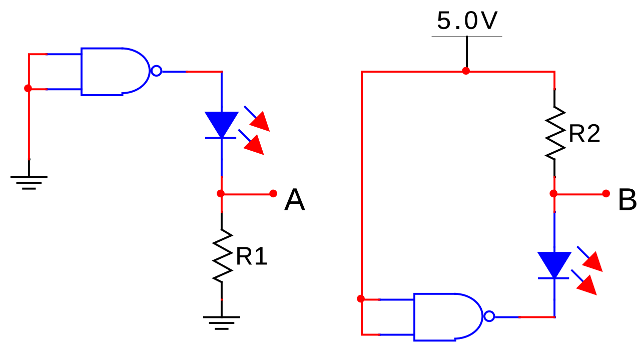

Figure 11. Active high on the left, active low on the right.

4.6 Analysis

1. Design a NOR function using one NAND gate and three inverters.
2. Design an XOR function using no more than three NAND gates and two inverters.
3. If a square wave is fed into one input to an XOR gate and the other input is tied high, will the output be the same as the input square wave or will it be inverted? What if the other input is tied low?
4. What does the latch do and how does it work? What do the S* and R* inputs do?
5. Is the LED brighter in the active low or the active high circuit?
6. Calculate the voltage across each resistor, VR1 = VA and VR2 = 5.0 – VB. Using Ohm's Law, I = V / R, calculate the current through each resistor and thus, through each the diode when it's on in the active high and active low configurations.

5 Device characterization

In this part of the lab, you'll discover the electrical characteristics of a real, as opposed to an ideal inverter. You'll measure the following.

1. Output voltages for various inputs.
2. The input voltage level at which the inverter switches.
3. How many nanoseconds it takes for a change on the input to cause a change in the output.
4. How many nanoseconds it takes for the output to change from low to high and high to low.

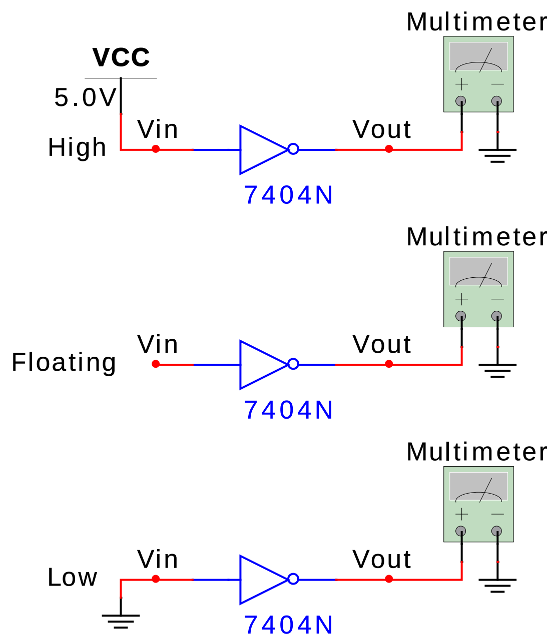

Figure 12. Measuring Vout with the input tied high, left floating (not connected) or tied low to ground (0 V).

5.1 TTL logic levels

Construct a table of measurements of Vout for a 7404 inverter with the input tied high, left floating and tied low as shown in figure 12.

5.2 Switching thresholds

Using the function generator to drive the inverter as in figure 13, set Vin = 5.0 Vpp +2.5 V offset 1 KHz triangle wave and check your setting on the oscilloscope.

Capture a screenshot similar of Vin and Vout with cursors positioned to measure Vin at the points where Vout begins to change and on-screen measurements Vin peak-to-peak and Vout min and max.

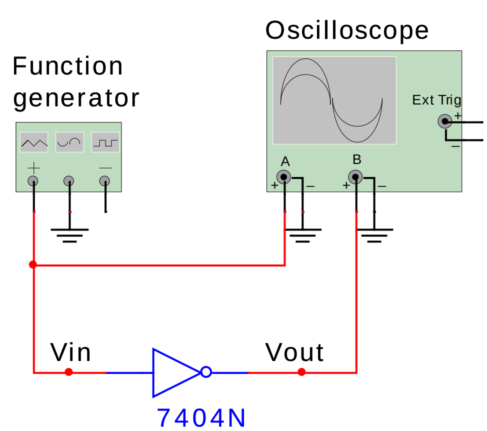

Figure 13. Measuring switching thresholds and transient response under no-load conditions.

5.3 Transient response

Using the function generator to drive the inverter, again as in figure 13, set Vin = 5.0 Vpp +2.5 V offset 1 MHz square wave and check your setting on the oscilloscope.

Capture screenshots on the oscilloscope of Vin on channel 1 and Vout on channel 2 with appropriate cursors and on-screen measurements of the following characteristics as shown in figures 14 and 15.

1. t_{PLH}, the propagation time from the 50% point on the input to the 50% point on the output for a low-to-high output transition.
2. t_{PHL}, the propagation time from the 50% point on the input to the 50% point on the output for a high-to-low output transition.
3. t_{RISE}, the time for the output to go from 10% to 90% rising.
4. t_{FALL}, the time for the output to go from 90% to 10% falling.

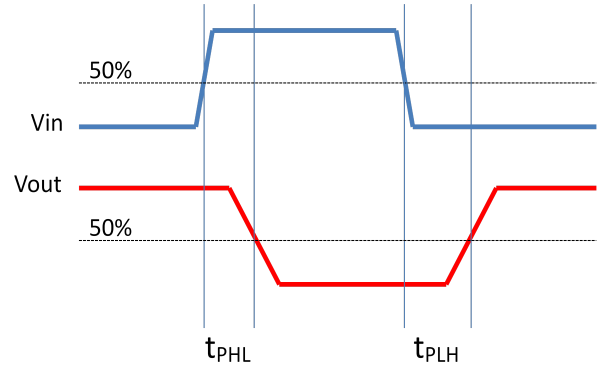

Figure 14. t_{PHL} and t_{PLH} are measured from input to output.

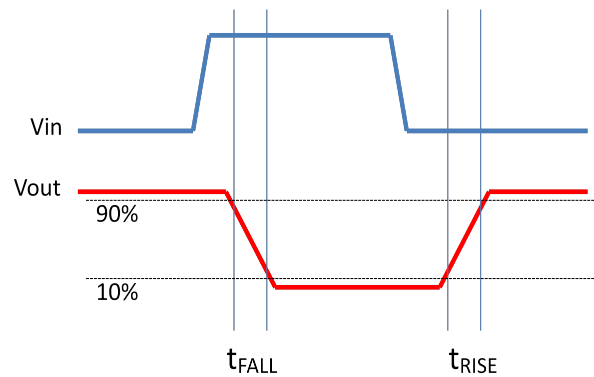

Figure 15. t_{FALL} and t_{RISE} are are measured on the output only.

5.4 Analysis

1. Compare your measured values for high and low output levels with the input switching threshold measured with the ramp. How much margin did you find between the high and low output levels and input threshold switching level?
2. When driven by a triangle, was the output a symmetric square wave? Why or why not?
3. Is a TTL device equally fast switching from high-to-low and low-to-high?

6 Ring oscillator

6.1 Circuit

Build the circuit in figure 16 using five inverters.

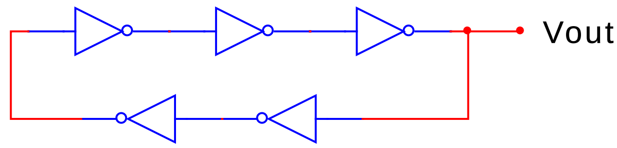

Figure 16. A ring oscillator.

6.2 Measurements

Capture screenshots of the output with on-screen measurements of frequency and peak-to-peak voltage.

6.3 Analysis

1. Explain how this circuit works.
2. Relate the output frequency and the shape of the waveform to the propagation and rise and fall times you measured for an inverter.

7 Hazards

Build the circuit in figure 17.

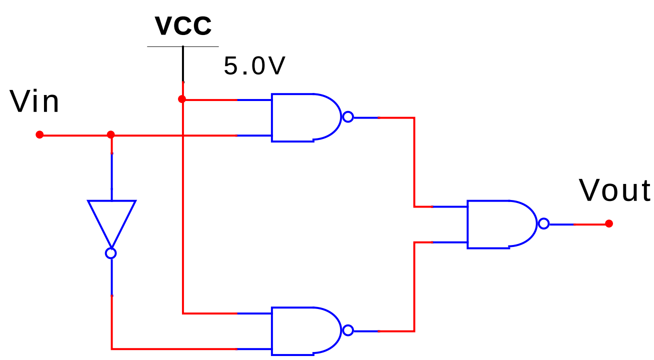

Figure 17. A circuit with a hazard.

7.1 Measurement

Set Vin = 5.0 Vpp +2.5 V offset 1 MHz square wave.

Capture screenshots of Vin and Vout with suitable cursors and on-screen measurements showing how the circuit behaves when Vin transitions low-to-high and high-to-low.

7.2 Analysis

1. What is the expected output for Vin high? For Vin low? When Vin changes from 1 to 0 or from 0 to 1, should Vout change?
2. What do observe?
3. Explain what you observed.
4. Why do you think this is called a hazard?