

Laboratory 3

Discrete logic gates. Measurements on digital signals.

3.1 Objectives

The objectives of this laboratory are the following:

- Rise time and fall time measurements on the digital signals;
- Propagation time measurements t_{pLH} and t_{pHL} of the signals through logic gates;

3.2 Definition of timing parameters of logic gates

Figure 3.1 shows how timing parameters of logic gates are defined.

- t_r - **rise time** of the input voltage (rise edge), measured between the 10% and 90% level of the amplitude of the input signal;
- t_f - **fall time** of the input voltage (fall edge), measured between the 10% and 90% level of the amplitude of the input signal;
- t_{HL} , t_{LH} - **transition time of the output signal between HL and LH states**, measured between the 10% and 90% level of the amplitude of the output signal;
- t_{PHL} , t_{PLH} - **propagation time from the input to the output** when the output switches between H (L) and L (H) states, measured on the horizontal axis between the points where the input and output signal passes 50% of its amplitude.

3.3 Measurements on the 7404 IC

The 7404 IC contains 6 inverters, implemented in TTL (Transistor-to-Transistor Logic) and located in the same package. The internal schematic of this IC is shown on figure 3.2.

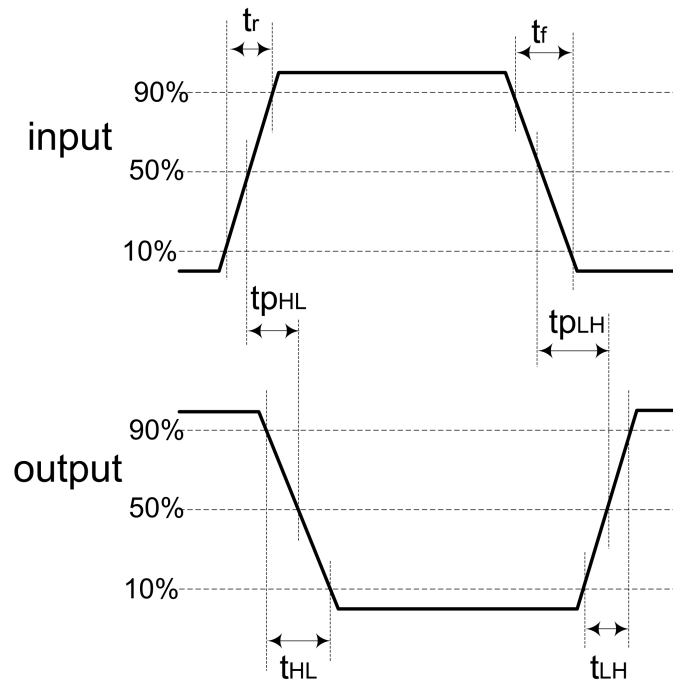


Figure 3.1 Definition of timing parameters.

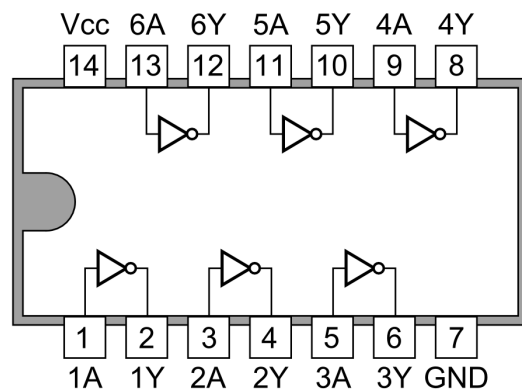


Figure 3.2 Internal schematic of the 7404 IC (6 inverters), TTL technology.

3.3.1 Measuring the propagation delay through an inverter

Implement the circuit shown in figure 3.3. Connect the 5V output of the Hameg power supply to the VCC pin of the IC.

Connect the output of the programmable function generator to the input of one of the inverters.

Choose the correct frequency of the input signal for the measurement you have to make (1 MHz?).

Connect the oscilloscope probes to the input (CH1) and output (CH2) of the inverter.

Using the oscilloscope measure and compare the rise time and fall time of the input and output signals. Measure the propagation delays t_{PHL} and t_{PLH} .

Repeat the measurements using an input frequency of 10 MHz. What you can observe related to the waveform of the output signal? What about the propagation delays?

Make sure to note the results for future reference.

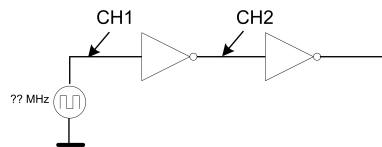


Figure 3.3 Circuit with one inverter.

3.3.2 Measuring the propagation delay through a chain of inverters

Disconnect the power supply from the IC.

Connect some inverters in a chain, as shown in figure 3.4.

Reconnect the power supply to the IC.

Measure the rise time and fall time of the output signal of the last inverter in the chain. Measure the propagation delay through the whole chain of inverters. Calculate the mean propagation delay of one inverter. Compare the result obtained by calculus with the one obtained by the earlier measurement. Analyse the precision of the measurements.

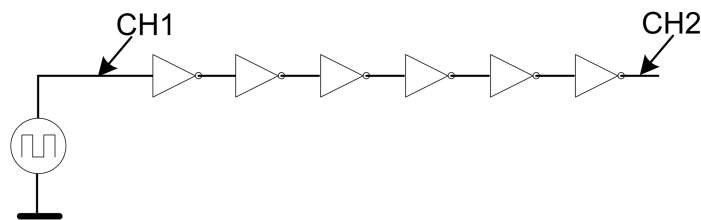


Figure 3.4 Circuit having 6 inverters connected in a chain.

3.3.3 Variation of the propagation delay with the frequency

Repeat the propagation delay measurements using different values for the frequency of the input signal. Fill the table 3.1 and analyse the results.

Table 3.1

Comparison of the propagation delay for different values of the input frequency.

Frequency	Period	Time/division	t_{PHL}		t_{PLH}	
			div	[ns]	div	[ns]
100 kHz						
200 kHz						
500 kHz						
1 MHz						

3.3.4 Variation of the propagation delay with the fan-out

Build a circuit consisting of one inverter driving the input of a different number of inverters, as shown figure 3.5.

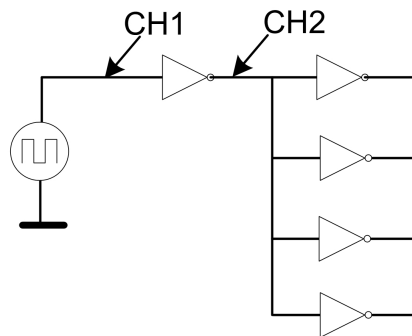


Figure 3.5 Circuit with an inverter having fan-out of 4 (FO4).

Fill table 3.2 and analyse the variation of the propagation delay with fan-out. Study the meaning of the notation FO4 (Fan Out Of 4).

Table 3.2

Study of the variation of propagation delay with the fan-out of the logic gate.

Fan-out	Time/division	t_{PHL}		t_{PLH}	
		div	[ns]	div	[ns]
1					
2					
3					
4					
5					

3.3.5 Circuit having an odd number of inverters connected in loop

Connect 5 inverters in a loop as shown in figure 3.6. Make presumptions and explain on the expected behavior of the circuit. Study the behavior of the circuit using the oscilloscope. Measure the oscillation frequency of the circuit. Explain the relationship between the oscillation frequency of the circuit and the propagation delay of an inverter.

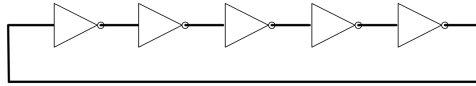


Figure 3.6 Circuit with 5 inverters connected in a loop - oscillating circuit.

3.3.6 Circuit having an even number of inverters connected in a loop

Connect 4 inverters in a loop as shown in figure 3.7. Make presumptions and explain on the expected behavior of the circuit. Study the behavior of the circuit using the oscilloscope. As you can suppose, the circuit has two stable states. Modify the circuit's state by connecting a piece of wire to the input of one of the inverters and the other end to the ground, thus forcing the state to logic 0. Repeat the experiment by connecting the wire to VCC, thus forcing the circuit's state to logic 1.

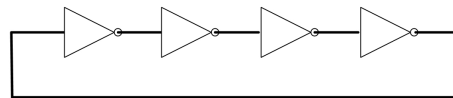


Figure 3.7 Circuit with 4 inverters connected in a loop - bi-stable circuit.

3.4 Measurements on the 4001 IC

The 4001 IC contains 4, 2-input NOR gates implemented in CMOS technology, integrated in the same package. The internal schematic of the IC is shown in figure 3.8.

Measure the propagation delays through a NOR gate. Make sure to connect 5V to VCC pin of the IC. Remind that these NOR gates have 2 inputs. So, connect one of the inputs to the ground and use the other input for the test signal.

Compare the propagation delays of logic gates implemented in CMOS and TTL technology.

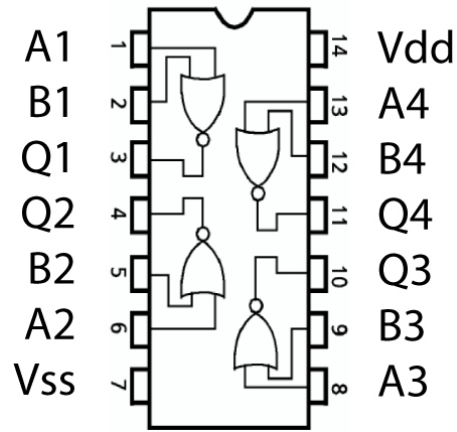


Figure 3.8 Internal schematic of the 4001 IC (4 NOR gates), CMOS technology.