

LC INVERTER Oscillator

Introduction

An oscillator is an electronic circuit that produces a periodic signal. They are fundamental elements in telecommunications, electronic test instrumentation, sequential digital systems, and numerous other applications. This exercise will examine an oscillator that produces a TTL type signal using a digital INVERTER and an LC filter. Such a signal would be appropriate for a digital sequential logic system.

Theory

There are two types of oscillators: feedback and relaxation. Feedback oscillators are circuits designed with linear circuits that have a gain of unity and a phase shift of zero at the desired frequency of oscillation; the circuit's output is connected to its input and it drives itself. Relaxation oscillators have one or more nonlinear components; the nonlinear component relaxes or stays in one state until the charging or discharging of a capacitor forces the circuit to the other state. A periodic output signal is produced with no input signal. The principle of the conservation of energy is not violated because the dc power supply is used to generate the signal.

An LC INVERTER oscillator is shown in Fig. 1.

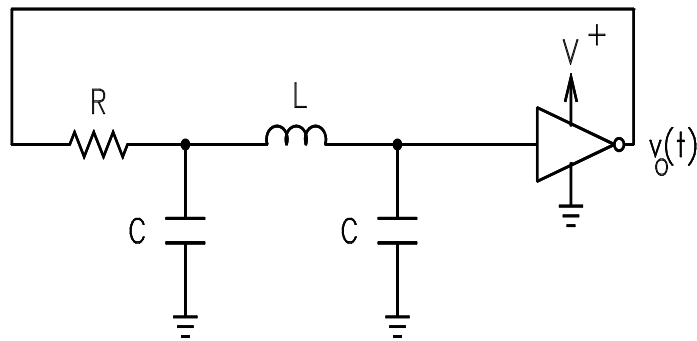


Fig. 1. LC INVERTER Oscillator.

The output of a digital INVERTER is connected to the input of a third order low pass filter whose output is connected to the input of the INVERTER. The output of the INVERTER is either ground (0 V) or V^+ . If $V^+ = 5$ V and the duty cycle of $v_o(t)$ is 50%, then $v_o(t)$ is a TTL signal. (TTL is a acronym for Transistor-Transistor-Logic which is a logic family that uses only power supply voltages of ground and +5 V). Basically the pulsed output of the INVERTER causes the LC filter to ring at a frequency at which the phase shift is 180° and

the gain is unity. The input to the INVERTER is a sine wave with a dc level of $V^+/2$ that is 180° out of phase with the TTL pulses being produced by the INVERTER. The low pass filter passes mostly the fundamental of the pulsed input which means that the input to the INVERTER is almost $(\frac{1}{2} + \frac{2}{\pi})V^+$. Thus it oscillates.

Shown in Fig. 2 is the circuit symbol and voltage transfer characteristic for an ideal INVERTER.

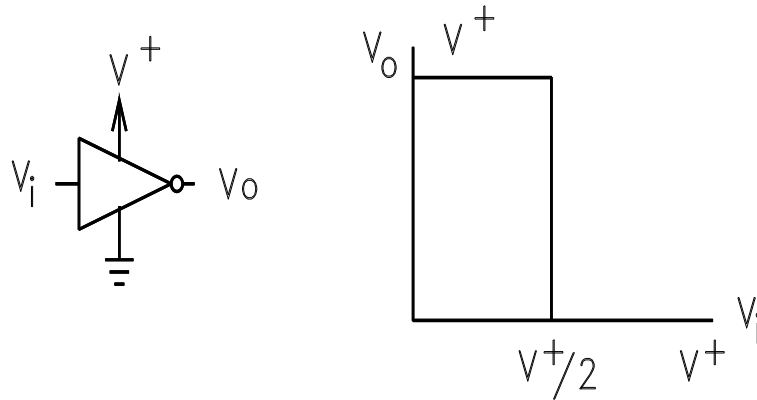


Fig. 2. Ideal INVERTER.

For input voltages less than half the power supply voltage the output is high and for voltages greater than half the power supply voltage the output is zero. The transition between the two states is for the input equal to half the power supply voltage. The power consumed by the ideal INVERTER is zero and the switching is instantaneous. Actual INVERTERS will obviously have characteristics that are compromises of these goals.

A very good INVERTER can be obtained using an N Channel Enhancement Mode MOSFET transistor as a switch and a P Channel Enhancement Mode MOSFET transistor as the load. This circuit shown in Fig. 3 is known as a CMOS INVERTER. Shown in Fig. 3 is the voltage transfer characteristic of a typical CMOS INVERTER with a power supply voltage of 5 V.

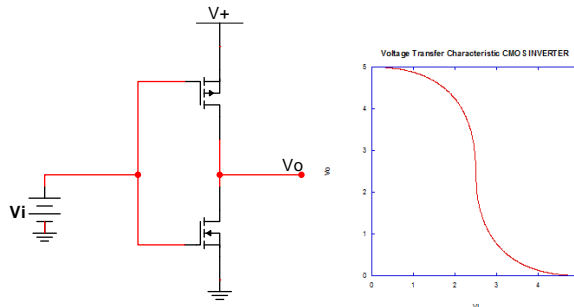


Fig. 3. CMOS INVERTER

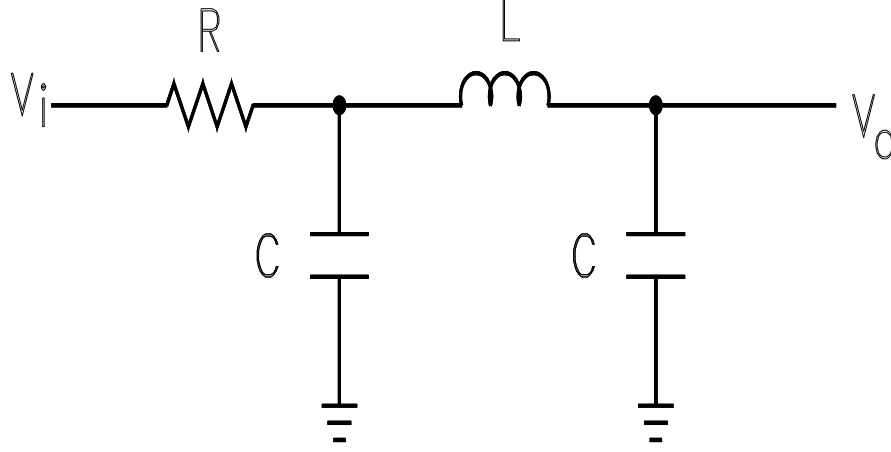


Figure 1: Fig. 4. LC Low Pass Filter.

When in the upper or lower state the power dissipation is zero but power is drawn from the power supply when it is switching states. The characteristic differs from the ideal but if the input or drive signal is large it suffices. Switching is not instantaneous due to the internal capacitances of these transistors.

Shown in Fig. 4 is the third order low pass LC filter that will be used for this oscillator.

The complex transfer function for this circuit is given by

$$T(s) = \frac{V_o}{V_i} = \frac{\frac{1}{sC} \parallel (sL + \frac{1}{sC})}{R + \frac{1}{sC} \parallel (sL + \frac{1}{sC})} \frac{\frac{1}{sC}}{sL + \frac{1}{sC}} = \frac{1}{s^3 RLC^2 + s^2 LC + 2RCs + 1}$$

which is a unity dc gain third order low pass filter. Thus the dc component of the input and output will be equal. To determine the frequency of oscillation, make the usual substitution of $s = j\omega$ which yields

$$T(j\omega) = \frac{1}{-j\omega^3 RLC^2 - \omega^2 LC + 2j\omega RC + 1}$$

for which the argument of $T(j\omega)$ is given by

$$\angle T(j\omega) = -\tan^{-1} \left(\frac{\omega RC [2 - \omega^2 LC]}{1 - \omega^2 LC} \right)$$

The phase will be 180° and the gain unity when

$$\omega = \omega_o = \sqrt{\frac{2}{LC}}$$

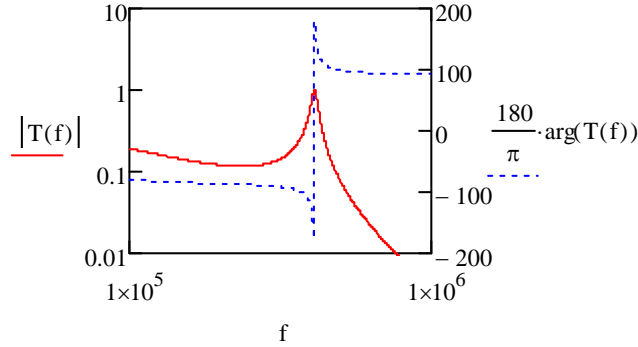


Figure 2: Fig. 5. Bode plot for $T(s)$.

which means the frequency of oscillation in Hertz is

$$f_o = \frac{1}{2\pi} \sqrt{\frac{2}{LC}}$$

Shown in Fig. 5 is a plot of the magnitude and phase of $T(s)$, viz., a Bode plot, for typical values that will be used in this experiment.

Note that the peak at $f = f_o$ is narrow which ensures that oscillations will only occur at this frequency.

This type of oscillator is capable of operating at higher frequencies than op amp oscillators which are hampered by finite gain bandwidth products. This oscillator is limited by only the internal capacitances of the devices and the parasitic capacitances of the connections. Frequently the inductor will be replaced with a quartz crystal which sets the frequency of oscillation very precisely. These types of oscillators are frequently found in digital systems as the clock signal or oscillator and is usually just referred to as a crystal oscillator.

Components

The digital INVERTER will be implemented using the CD4007 integrated circuit from the hoary 4000 logic family. This device has 3 N and 3 P MOSFETs. The dc power supply voltage will be 5 V. The resistor $R = 43 \text{ k}\Omega$ and the inductor $L = 3 \text{ mH}$. The capacitor C will be determined by the last non numeric digit in the experimenter's GT No.

GT No.	$C(pF)$
0	10
1	15
2	22
3	33
4	39
5	47
6	68
7	100
8	220
9	330

Procedure

- Measure the value of the resistor, inductor, and capacitor with the RLC meter. For the inductor measure the series resistance with the digital multimeter and the RLC meter.
- Compute the frequency of oscillation using

$$f_o = \frac{1}{2\pi} \sqrt{\frac{2}{LC}}$$

Use the measured value for L and the average of the two capacitor values for C .

- Use the laboratory equipment to plot the gain and phase of the low pass filter one decade below and one decade above f_o . If the automated measurements program does not yield satisfactory results make the measurement manually.
- Assemble the oscillator circuit. Measure the frequency of oscillation by printing the oscillogram of the output of the INVERTER and the output of the filter.
- How may the output of the INVERTER be improved? Namely, how may it be made to look more like an ideal TTL signal? Hint: the solution is on the breadboard.

Simulations

- Use SPICE and Mathcad to plot the magnitude and phase of the complex transfer function for the third order low pass filter.
- Use SPICE to simulate the oscillator. Perform a transient analysis. Plot both the input and output of the INVERTER. For the transistors use the values of the SPICE parameters obtained in Experiment 7, viz., the value of K , V_{TO} , and λ that were determined from the curve tracer data.

Report

Prepare the report using the style specified by the Writing Instructors. Include all data taken, viz., the values of the passive components measured, the Bode plots, and the waveforms produced by the oscillator.

Compare the theoretical, simulation, and experimental results. Provide explanations of any significant differences in terms of sources of error.

How would the results have differed if an INVERTER from another logic family been used?

How would the results have differed if the dc power supply voltage was increased?

What advantage does CMOS logic have over TTL logic and vice versa?

Georgia Institute of Technology

School of Electrical and Computer Engineering

ECE 3042

Electrical and Electronic Circuits Laboratory

Verification Sheet

NAME: _____

SECTION: _____

AD LOGIN: _____

INVERTER Oscillator

Procedure	Time Completed	Date Completed	Verification (Must demonstrate circuit)		
Bode Plot of Filter					
Time Domain Screen Shot of Oscillator Output					
Spectra of Output of Oscillator					

Enter your critical frequency below:

<i>Last Digit of GTID</i>	
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SIGNATURE: _____

DATE: _____