YILDIZ TECHNICAL UNIVERSITY

Department of Electronics and Communications Engineering

EHM2131 - Electromagnetic Field Theory

Term Project:

Design and Implementation of a Fluid Gauge

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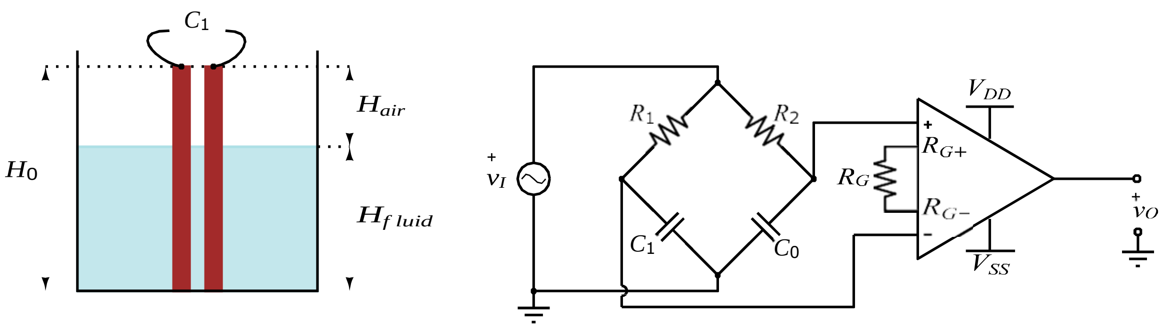
1 Project Overview

The height of a fluid in a closed tank can be inferred from capacitance measurement as illustrated in Figure 1a. The capacitance between the plates is C_0 when the tank is empty, and C_1 when the tank is filled with fluid. As shown in previous lectures, the height of the fluids is directly proportional to the capacitance between the plates. This capacitance is measured through a bridge circuit shown in Figure 1b.



(a) (b)

Figure 1: a) Measurement of fluid height in a tank. b) Bridge Circuit for capacitance measurement.

2 Procedure

The project involves three steps:

Step 1: Take a 5 liter plastic bottle and cut its upper section to create a tank as exemplified in Figure 2. Measure the exact height of your tank. Take two pieces of metal plates that you can submerge into water with a fixed plate separation. (You may glue a plastic spacer between the plates so that the distance is fixed.) Firstly, calculate theoretically the capacitances at home when the tank is empty and full water in between the plates. In laboratory, you will measure the capacitances of the plates for two cases (empty and full cases) with given described method below (see Section 3). Please fill in the blanks given below with your measurements:

C_0: (Measured Capacitance when the tank is empty) .... F

C_1: (Measured Capacitance when the tank is full) .... F

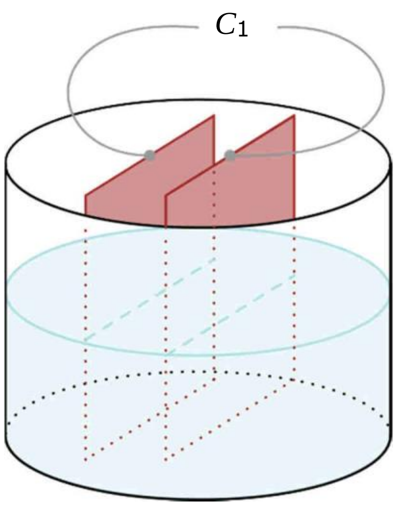


Figure 2: Two Parallel Plates in a Cylindrical Tank.

Step 2: Using your favorite circuit simulator, build the circuit shown in Figure 3. Set the amplitude of the AC voltage source as 0.25V. Set the capacitances C_0 and C_1 with your theoretical values found in Step 1. Select an initial value R for the resistors R_1 and R_2. Perform an AC sweep starting from 1Hz to 1GHz with 100 points per decade. When the voltages $v(1)$, $v(2)$ and $v(1) - v(2)$ ~~is~~ plotted as a function of frequency, the result is similar to the graph shown in Figure 4.

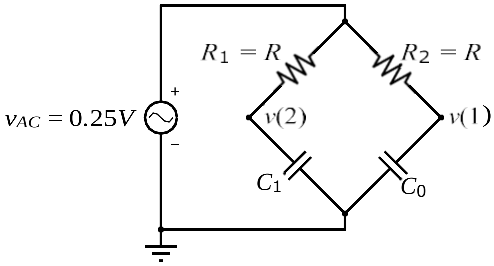


Figure 3: Simple Bridge Circuit

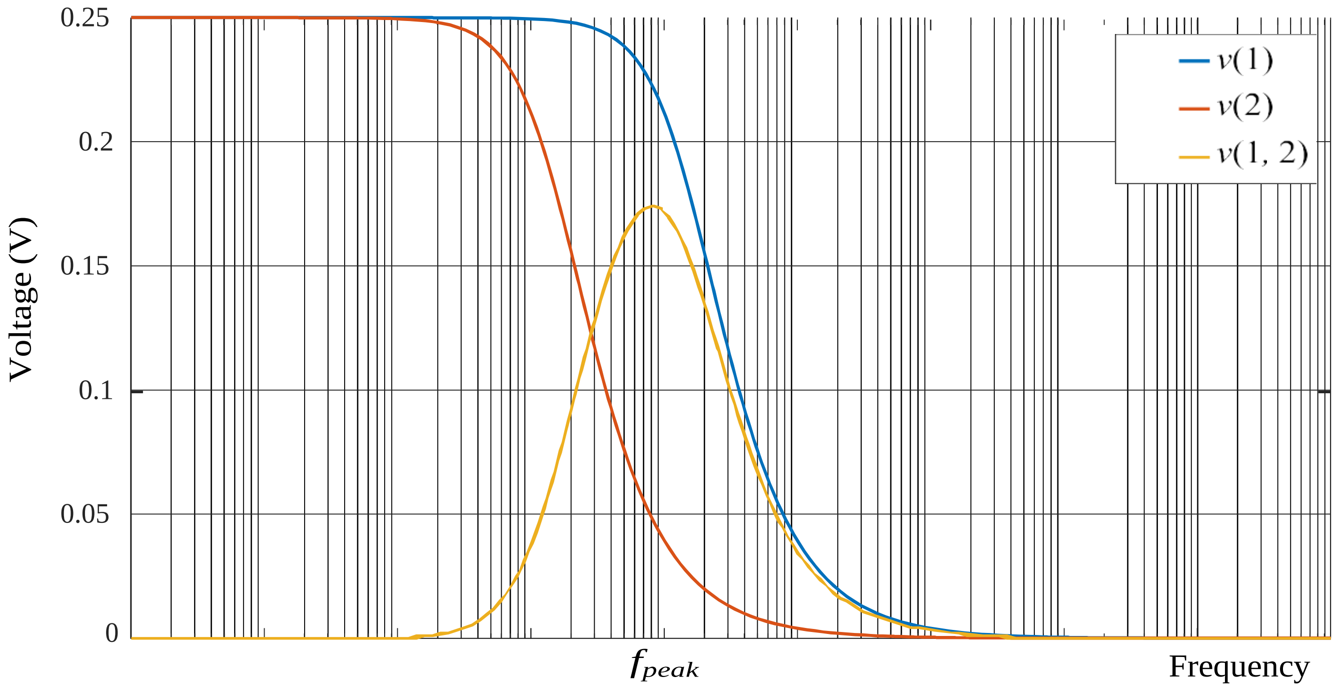


Figure 4: Bridge circuit output voltages as a function of frequency.

As can be seen in Figure 4, the differential voltage "$v(1)$ - $v(2)$" reaches its maximum for a specificfrequency f_{peak}. Adjust R to an appropriate value for f_{peak} to fall somewhere between 1-10kHz. This is important for the rest of the circuit since every operational amplifier has a limited bandwidth. Fill in the appropriate resistor value R and the resulting peak-frequency f_{peak} to the blanks given below.

R :............. Ω, f_{peak} .... Hz

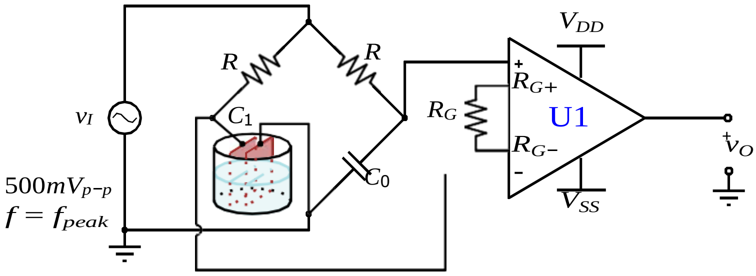


Figure 5: Top-Level System Schematic.

Step 3: Top-Level system architecture is shown in Figure 5. "U1" represents the instrumentation amplifier, which is a type of differential amplifer mostly used in applications where great accuracy is needed. You may purchase an instrumentation amplifier (AD620, INA114 etc..) or build your own instrumentation amplifier with standard opamps as a low-cost solution[1]. Set R_G such that the gain of instrumentation amplifier is high enough to measure the output. A gain of 5 to 10 may be enough for good signal seperation on the oscilloscope. Apply a $500mV_{p-p}$ sinewave with a frequency f_{peak} found in Step 2. Replace C_0 and R with the values found in Step 1 & 2. Set DC positive (V_{DD}) and negative (V_{SS}) power supplies to an appropriate value using the datasheet of your amplifier.

Take 5 measurements with the conditions given in Table 1. Fill-in the "Expected Output" section by accurately estimating the capacitance in the tank and simulating the top-level architecture. Carefully show all of your calculations and simulations for each case. Fill-in the "Actual Output" section by measuring the output of the instrumentation amplifier for each case. Calculate the error for each measurement and sum of squares of errors.

Table 1: Performance Summary.

	Expected Output (V_{p-p})	Actual Output (V_{p-p})	Error (V_{p-p})
Empty Tank			
(1/4) Filled with water			
(1/2) Filled with water			
(3/4) Filled with water			
Full Tank			

Sum of square of errors (SSE): ....

3 Capacitance Measurement

The measurement arrangement is shown in Figure 6. This is a half bridge configuration consisting of the resistor R and the unknown capacitor C. The method is based on finding the cutoff frequency of a RC filter. The cut-off frequency is the frequency at which the output power is halved and is indicated by the power level of −3 dB. A sample frequency characteristic of a RC filter is also given in Figure 6. Use the sine wave in the function generator and keep the frequency lower than the cut-off frequency. In this case, you will see successive sine waves in the channels of the oscilloscope as seen in Figure 6. In order to determine unknown capacitor value, you must increase the frequency until it catches the cutoff frequency of RC filter. The amplitudes of the measuring voltages should change as the frequency increases and should be zero for higher frequencies than cut-off frequency of the low-pass filter. When you reach the cutoff frequency, the ratio between the voltage values should be 0.707 as given in equation (3). You should observe this situation by changing the frequency of the sine wave in the function generator.

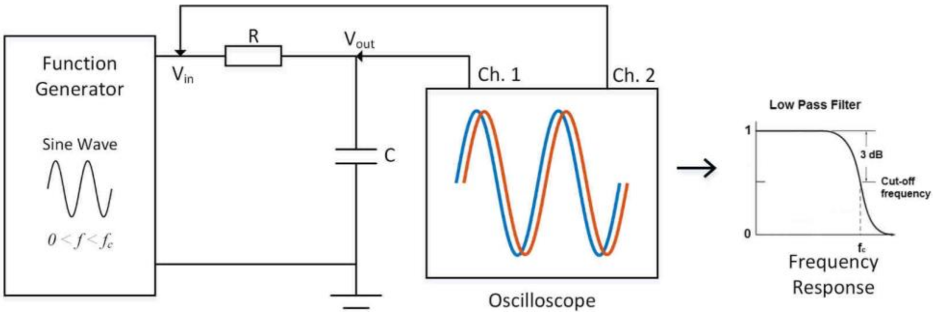


Figure 6: Measurment System Schematic.

The cut-off frequency easily calculates as below:

$$f_c = \frac{1}{2\pi RC} \tag{1}$$

The voltage changes at the cut-off frequency should be:

$$10\log\left(\frac{|V_{out}|^2}{|V_{in}|^2}\right) = \text{-3 dB} \tag{2}$$

By using the equation (2), we can find the voltage ratio for cut-off frequency:

$$\frac{|V_{out}|}{|V_{in}|} = 0.707 \tag{3}$$

A Capacitance Measurement Example:

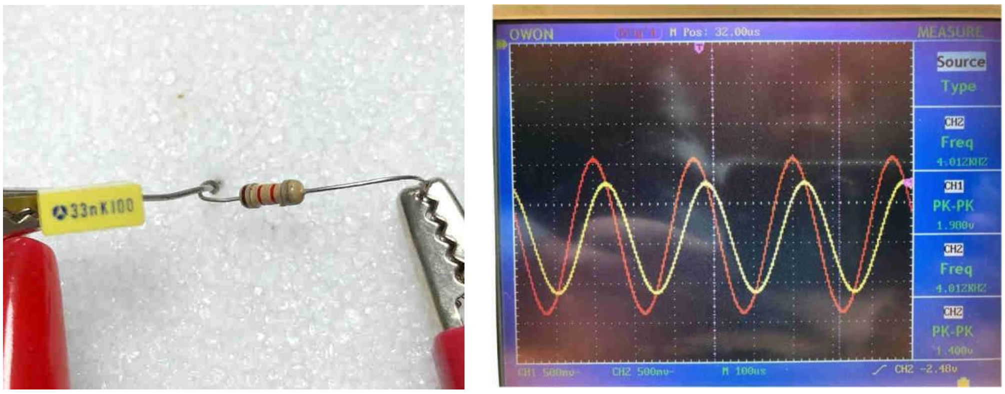


Figure 7: An Example of RC Filter.

Now, we set up a RC filter as in the Figure 7 (R = 1.2 kΩ). Then using function generator we give a sine wave at 2V peak-to-peak value as V_{in} and it is shown by red color wave (CH1) in the Figure 7. Using an oscilloscope, we measure the V_{out} value that is shown by yellow color (CH2). We would like to estimate the cut of frequency where V_{out} and V_{in} satisfy the equation (3). To do this we change the frequency of the function generator until we obtain V_{out} = 1.4 V [see equation (3)]. Finally, we find desired C value as 33 nH.

4 Remarks

This is a group project (a group of 3 students) to be completed in 1-laboratory session. Therefore, choose two friends to work with for this project. Follow the announcements for laboratory allocation and do not miss the date assigned to you. There will be no make-up session and each group will work in the laboratory only in their assigned date. All group members should participate the laboratory sessions.

Laboratory assistant will announce the date and time that you can work in the laboratory. You cannot use the lab for this project in any other date and time.

All necessary preparations (adding contacts to the plates, glueing, soldering etc...) belongs to the group itself. Do not request help or equipment from your instructors.

Considering the price of an instrumentation amplifier, you can share your electronic circuit components with your friends. (Just components, not the whole circuit). You can also share your 5lt plastic bottle with your friends. The parallel-plate capacitor; however; should be unique to each group where the group member names must be written on with a permanent pen.

[1] See Wikipedia: https://en.0wikipedia.org/wiki/Instrumentation_amplifier

5 Report Writing

Your report should be written using Word Processor Programs. Your equations (use equation editor), your tables and your figures need to be written and drawn with computer (not with your hands.) Do not forget to include the references you have used in your report. Your report should be written in such a nice flow that anybody who reads it should understand it clearly. You need to write one paragraph at the end of your report to explain how you have worked as a team to achieve the goal of this project, that is, specify who did what.

6 Deliverables

Each group will deliver the report to the assistant of the instructor. No other formats will be accepted. The deadline date will be announced and not be extended. Each day after deadline will cause 50% reduction of your grade. Therefore, plan ahead and do not pressure yourself by postponing your work until the day of submission.

7 Result Sheet

Since all the groups are allowed to work in laboratory only in assigned time; it is important for the instructor to keep each group's measurement data, to ensure that no additional work or change has been performed on the measurements. Each group, therefore, will fill a result sheet in each session and give a copy to the instructor.

C_0: (Measured Capacitance when the tank is empty) .... F

C_1: (Measured Capacitance when the tank is full)............. F

Table 2: Measurement Results.

	Actual Output (V_{p-p})
Empty Tank	
(1/4) Filled with water	
(1/2) Filled with water	
(3/4) Filled with water	
Full Tank	

This section belongs to instructor.

Student Number	Student Name	Session-1	Session-2

C_0: (Measured Capacitance when the tank is empty) .... F

C_1: (Measured Capacitance when the tank is full)............. F

Table 3: Measurement Results.

	Actual Output (V_{p-p})
Empty Tank	
(1/4) Filled with water	
(1/2) Filled with water	
(3/4) Filled with water	
Full Tank	