Table of Contents

Signal conditioner for capacitive and inductive sensors.

Chávez Hernández Carol Monserrat
ESCOM – IPN
cchavezh1900@alumno.ipn.mx

Moreno Martínez Diego Alejandro
ESCOM – IPN
dmorenom2002@alumno.ipn.mx

Giles Macías Alexis
ESCOM – IPN
agilesm1700@alumno.ipn.mx

Abstract – The Blumlein bridge, named after its inventor Alan Dower Blumlein, is a specialized AC bridge known for its exceptional sensitivity in measuring capacitance changes. It's particularly well-suited for applications involving capacitance transducers, devices that convert physical quantities like pressure, strain, or displacement into changes in capacitance.

Signal conditioning of inductive sensors to obtain an output proportional to the change in the inductance alone is fraught with problems. The large value of self-inductance that is present in a sensor coil and the change in the inductance being a small fraction of this large inductance coupled with the winding resistance of the sensor coil make signal conditioning of such inductive sensors a challenge

I. Introduction

The basic component of capacitive sensors is the capacitor with capacitance C. If we have a setup where there are any number of electrodes, the capacitance between them is the quotient of the set on charge in one of them divided by the difference in voltage between them. You can look at Figure 1 and (1) to get this [1].

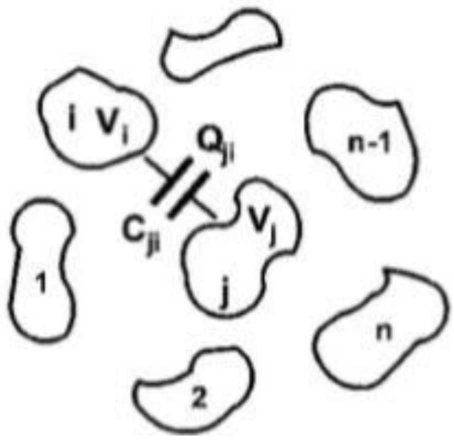


Figure 1 Representation is mainly used to show the capacitance between two conductors.

$$C_{ji} = \frac{Q_{ji}}{V_j - V_i} \quad (1)$$

Capacitance variation in capacitors with parallel plaques

Simple capacitor

In this case, the capacitance value could be changed by the plaques' distance into the capacitor (x), their area (A) or the kind of dielectric (ε). When the variations between plaques are present. The equation 2 describes the behaviour of capacitance and its impedance [1].

$$C = \frac{\varepsilon A}{X}\ ;\ |Z| = \frac{1}{\omega C} = \frac{X}{\omega \varepsilon A} \quad (2)$$

It means the capacitance isn't linear over the plaques' distance, on the other hand, the distance is.

The capacitance's sensibility when the distance between plaques is getting narrow or expansive is shown by (3)

$$\frac{dC}{dX} = -\varepsilon \frac{A}{X^2} \quad (3)$$

Differential capacitor

A differential capacitor is made with three parallel plaques, in general, the plaques on each side are fixed and the centre plaque is movable to detect these changes, in the Figure 2 This description is shown.

This way, two capacitors are built, and their value is determined with (4) and the entire differential capacitance is given by (5).

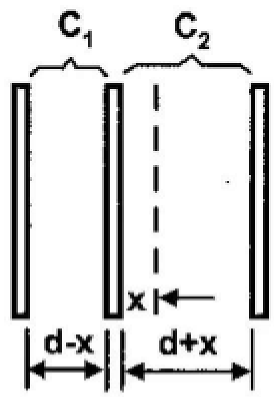


Figure 2 Differential capacitor

$$C_1 = \varepsilon \frac{A}{d - X}\ ;\ C_2 = \varepsilon \frac{A}{d + X} \quad (4)$$

$$C_1 - C_2 = \frac{2\varepsilon A}{d^2 - X^2} X \quad (5)$$

AC bridges

Changes in capacitive sensor capacity can be measured using alternating bridges.

These bridges are, as we will see, especially attractive in the case of the differential capacitor. Figure 4 shows the case of an alternating bridge in which the capacitors C and C are arranged in adjacent branches, the other two branches being occupied by resistors of equal value. The equation (6) shows the output voltage of this bridge [1].

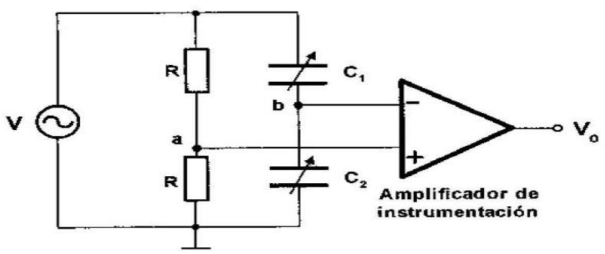


Figure 4 AC bridge

$$V_{ab} = V\left(\frac{1}{2} - \frac{C_1}{C_1 + C_2}\right) \quad (6)$$

If the bridge output is detected with a high-input impedance circuit (e.g., by instrumentation amplifier), the relationship between the bridge output and the displacement is linear. The bridging structure provides an additional advantage, as any simultaneous changes to adjacent branches are cancelled out (e.g., external interference, thermal drift, etc.). On the contrary, the resistive arms of the bridge introduce errors due to the parasitic capacities of these resistances. Its effects can be reduced by a bridge whose arms are inductive, as shown in Figure 5. The output voltage is described in (7) [1].

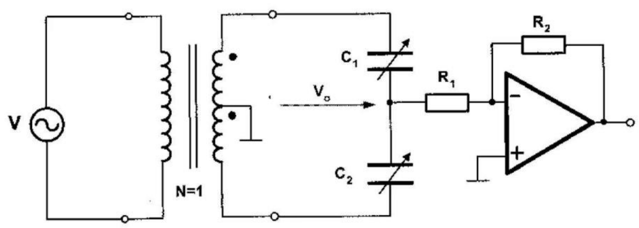


Figure 5

$$V_o = \frac{V}{2}\left(\frac{C_1 - C_2}{C_1 + C_2}\right) \quad (7)$$

Inductive sensors

In a way equivalent to how potentiometers and capacitors are used as electronic sensors when the variable to be measured affects one of its characteristic parameters, inductive devices can also be affected by certain variables and, therefore, can also be used similarly; logically, the operating principles are different and so the measuring circuits, in inductive systems, the parameter that will be handled will be the value of the self-induction L of the device, although, given the possibilities of transferring signals between several windings, this type of element will have other possibilities such as those derived from the use of the coupling factor as a variable.

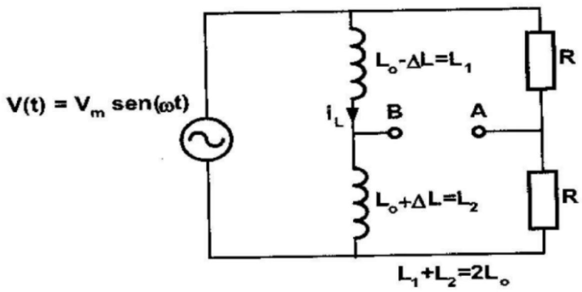


Figure 3 Measurement circuit

Measurement circuits

The measurement circuits for this type of sensor are like those used in capacitive sensors; It will be an alternating measurement, and any of the techniques used with them can be used, such as voltage measurement in a current-excited system, current measurement in a voltage-excited system, resonant or bridge circuits. In all these cases, let us remember that the excitation must be constant not only in the voltage value but also in frequency, In the particular case of inductive sensors such as those of the Figure 3, with a topology with two windings and a differential type behaviour, in which one of the coils suffers an increase in the value of its L and the other, a decrease [1].

In general, the output voltage for this bridge is described in (8) and if we are using RMS values (9) is used.

$$V_B - V_A = \frac{\Delta L}{2L_0} V_m sen(\omega t) \quad (8)$$

$$V_{out} = \frac{V_m}{2}\left(\frac{L_1 - L_2}{L_1 + L_2}\right) \quad (9)$$

II. Objective

The student will implement alternating current bridge circuits for the conditioning of variable ballast sensors.

III. Tools used for it

- A computer
- A circuit simulation software like Multisim or Proteus

IV. Content

Capacitive sensor

In the Circuit Simulation Software Tool, the circuit in Figure 6 Is assembled using capacitors as differential capacitive sensors. Determine the minimum and maximum capacitance values required in the differential capacitive sensor, considering that the AC bridge circuit must deliver a maximum output voltage of ±1.5V effective and that it develops capacitances of 90pf in equilibrium.

Adjust the capacitive values with the calculated value and then to the transformer to deliver an effective 5V voltage at a frequency of 60HZ. Check the operation of the circuit by measuring the minimum and maximum output voltage of the bridge circuit with an AC voltmeter.

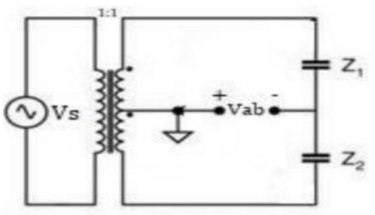


Figure 6

We've decided to use the Multisim software to simulate Blumlein's bridge, so we must get ±1.5v rms in the AC output, we do know when the bridge is balanced, both capacitors of the differential sensor are equal to 90pf, so $C_2 = 90pf + \Delta C$ and $C_1 = 90pf - \Delta C$ So, these conditions are shown in (2). Besides that, in (3), (4), (5) and (6) the steps to get the capacitance increment are shown.

$$\mathbf{1.5V = \frac{5}{2}V\left(\frac{(90pf + \Delta C) - (90pf - \Delta C)}{90pf + \Delta C + 90pf - \Delta C}\right)} \quad \textbf{(10)}$$

$$\mathbf{1.5V = \frac{5}{2}V\left(\frac{2\Delta C}{180pf}\right)} \quad \textbf{(11)}$$

$$\mathbf{\frac{3}{5} = \left(\frac{\Delta C}{90pf}\right)} \quad \textbf{(12)}$$

$$\mathbf{18pf * 3 = (\Delta C)} \quad \textbf{(13)}$$

$$\mathbf{54pf = \Delta C} \quad \textbf{(14)}$$

So, that means the upper limit will be 90pf + 54pf = 144pf and lower limit 90pf – 54pf = 36pf.

In the Table 1 Output voltage with this capacitance increment is shown.

C_1	C_2	V_{ab}
144pf	36pf	±1.5v
90pf	90pf	0v
36pf	144pf	±1.5v

Table 1 Capacitances in the differential sensor

For simulating values, we've set a variable capacitor with a maximum value of 150pf. To get 144pf from 150pf, it must be set up to 96%, and to get 36pf, it must be set up to 24%.

The Figure 7, Figure 8 and Figure 9 show this differential capacitor setting up over these values, and when it's balanced.

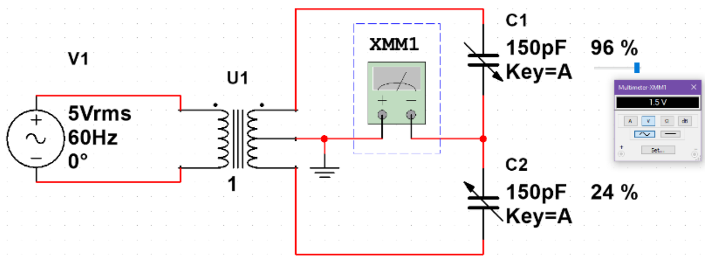


Figure 7

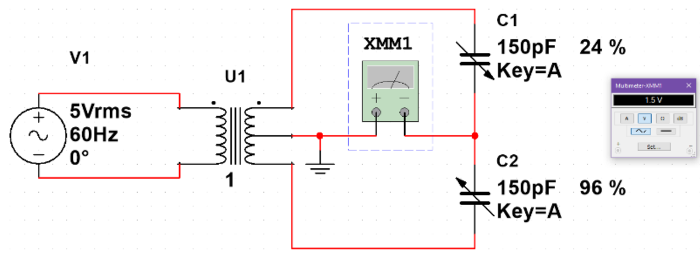


Figure 8

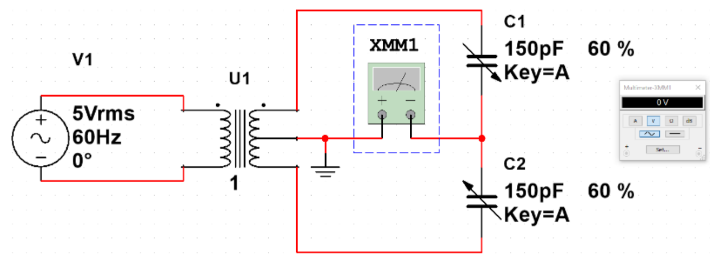


Figure 9

Inductive sensor

In the Circuit Simulation Software Tool, assemble the circuit in Figure 10 Using the inductors as a differential inductive sensor. Determine the resistive values, as well as the minimum and maximum inductance values required, in the differential inductive sensor, considering that the AC bridge circuit must deliver a maximum output voltage of ±1.5V effective and that in equilibrium it develops inductances of 50mH.

Adjust the resistive values as well as the inductive values with the calculated value and subsequently to the AC source to deliver an effective voltage of 5V at a frequency of 60HZ.

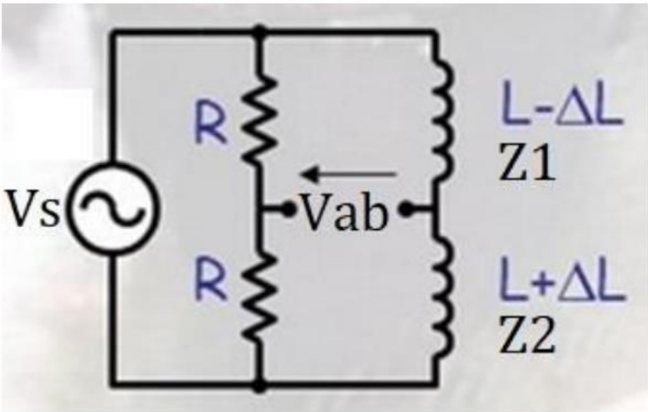


Figure 10

We do know the inductor impedance is defined by (15), so we can get a value written in Ohms to get the resistor value, this is $|Z| = 2\pi f L \rightarrow |Z| = 2\pi(60Hz)(50mH) \approx 18.849\Omega$

$$\boldsymbol{Z = j\omega L} \qquad (15)$$

So, we've set a 20Ω potentiometer set up to 94.24% for getting near this value. Next is getting the inductance increment, (16), (17)

$$\boldsymbol{1.5V = \frac{5}{2}V\left(\frac{(50mH + \Delta L) - (50mH - \Delta L)}{50mH + \Delta L + 50mH - \Delta L}\right)} \qquad (10)$$

$$\boldsymbol{1.5V = \frac{5}{2}V\left(\frac{2\Delta L}{100mH}\right)} \qquad (11)$$

$$\boldsymbol{\frac{3}{5} = \left(\frac{\Delta L}{50mH}\right)} \qquad (12)$$

$$\boldsymbol{10mH * 3 = (\Delta L)} \qquad (13)$$

$$\boldsymbol{30mH = \Delta L} \qquad (14)$$

Finally, in the Figure 11, Figure 12 and Figure 13 shows the simulation results and the [] too.

L_1	L_2	V_{ab}
80mH	20mH	±1.5v
50mH	50mH	0v
30mH	80mH	±1.5v

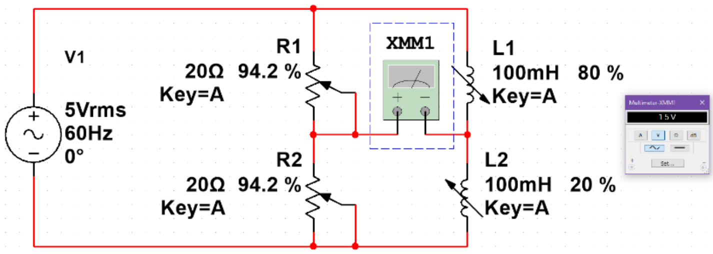


Figure 11

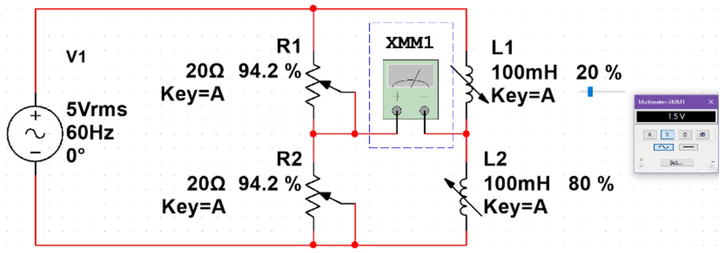


Figure 12

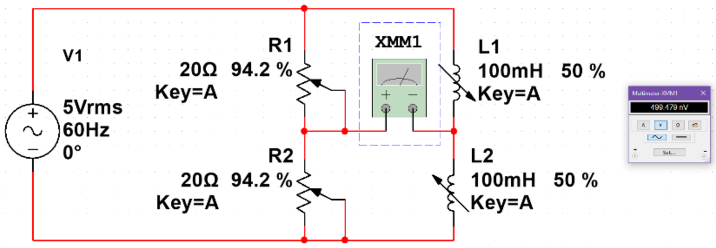


Figure 13

V. Questionnaire

What is the reactance?

In electrical circuits, reactance is the opposition presented to alternating current by inductance and capacitance.

Reactance is used to compute amplitude and phase changes of sinusoidal alternating current going through a circuit element. Like resistance, reactance is measured in ohms, with positive values indicating inductive reactance and negative indicating capacitive reactance.

How are variable electrical reactance sensors classified?

Capacitive Sensors: These sensors measure changes in capacitance. They are often used for detecting proximity, position, and level measurements.

Inductive Sensors: These sensors measure changes in inductance. They are commonly used for detecting metallic objects and measuring position or speed.

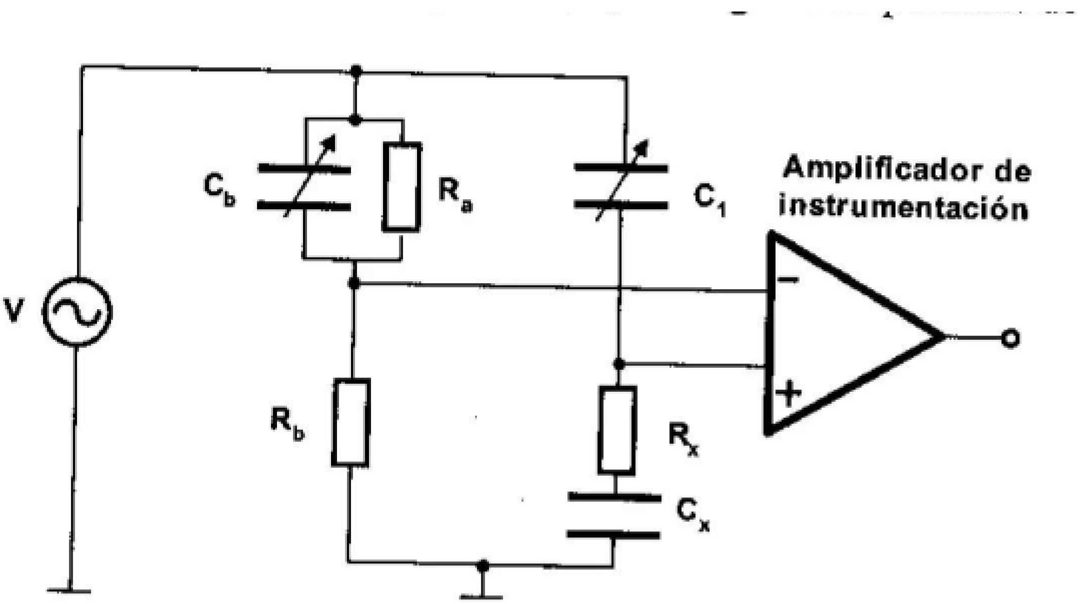
Electromagnetic Sensors: These sensors use electromagnetic fields to measure displacement or position. Examples include LVDT (Linear Variable Differential Transformer) sensors.

Piezoelectric Sensors: While not strictly reactance-based, these sensors can be used in conjunction with capacitive or inductive elements to measure mechanical changes.

What are some quantities that can be measured with variable ballast sensors?

- **Particle Count**: Monitoring the number of particles in the ballast water to ensure proper filtration.
- **Chlorophyll Fluorescence**: Measuring the presence of algae and other organic matter to assess the effectiveness of disinfection processes.
- **Turbidity**: Evaluating the clarity of the water, which can indicate the presence of suspended solids.
- **Temperature**: Monitoring the temperature of the ballast water, which can affect the survival of organisms.
- **Salinity**: Measuring the salt content in the water, which can impact the treatment process.
- **pH Levels**: Assessing the acidity or alkalinity of the ballast water.
- **Oxygen Levels**: Measuring the dissolved oxygen content, which is important for the survival of marine organisms.

Draw a general scheme of variable electrical reactance sensors circuit conditioner



VI. Conclusions

Chavéz Hernández Carol Monserrat

Capacitive and inductive sensors, when properly conditioned, offer robust and reliable solutions for a wide range of industrial and commercial applications. The process of signal conditioning—such as amplification, filtering, and linearization—enhances the precision and usability of these sensors, making them ideal for detecting position, speed, and presence of objects. By addressing the specific needs of each application, engineers can leverage the full potential of capacitive and inductive sensors to achieve accurate and consistent measurements.

Moreno Martínez Diego Alejandro

The conditioning of capacitive and inductive sensors plays a crucial role in their performance and accuracy. Through the use of advanced signal conditioning techniques, such as compensation for environmental factors and signal processing algorithms, these sensors can deliver high-quality data even in challenging conditions. This makes them invaluable in applications requiring precise measurements, from automation and robotics to environmental monitoring. The continuous improvement in sensor conditioning technologies ensures that capacitive and inductive sensors remain at the forefront of measurement solutions.

Giles Macias Alexis

Effective conditioning of capacitive and inductive sensors is essential for optimizing their functionality and expanding their application scope. Techniques like noise reduction, calibration, and integration with microcontroller systems allow these sensors to provide accurate and reliable measurements. As technology advances, the development of more sophisticated conditioning methods will further enhance the performance of capacitive and inductive sensors, making them indispensable tools in fields such as aerospace, automotive, and consumer electronics.