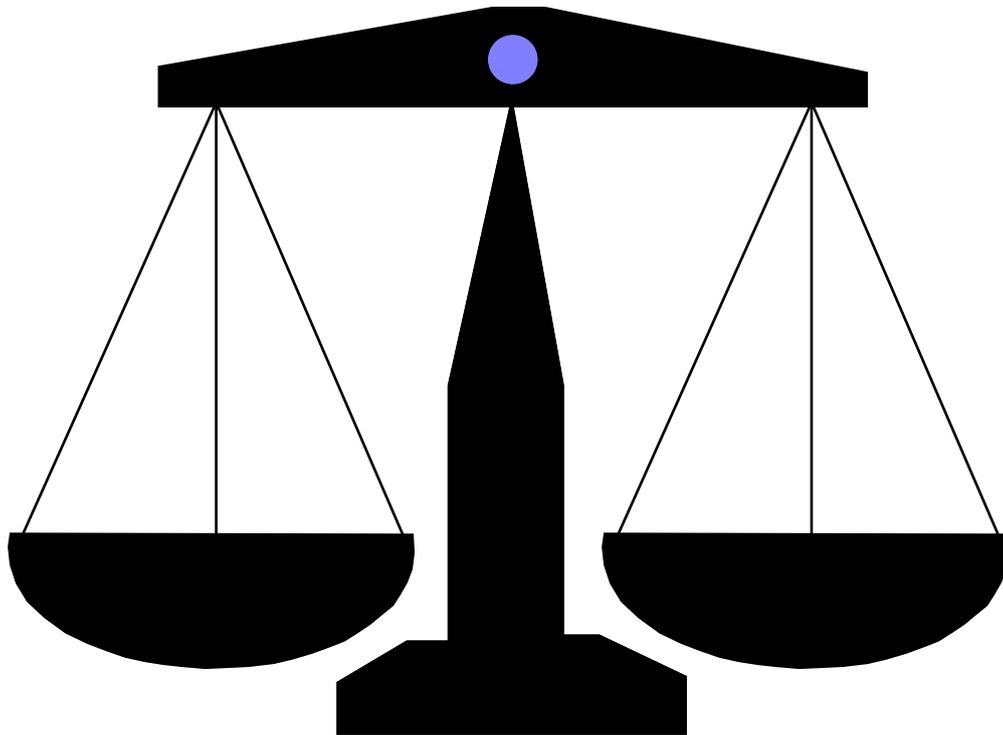




**Mittuniversitetet**

MID SWEDEN UNIVERSITY

# **SENSOR AND MEASUREMENT EXPERIMENTS**



# Contents

1. **Capacitive sensors**
2. **Temperature measurements**
3. **Signal processing and data analysis using LabVIEW**
4. **Load measurements**
5. **Noise and noise reduction**
6. **Instructions for reports and oral presentation**

# Appendix

**AD620 Data sheet**

**Model 1022 Single Point Aluminum Load Cell data sheet**

# 1 Capacitive sensors

## 1.1 Objective

In this experiment you will learn how to design a simple capacitance-sensing detector. You will also get familiar with one type of capacitive sensor for measuring the level of a liquid.

## 1.2 Detector circuit theory

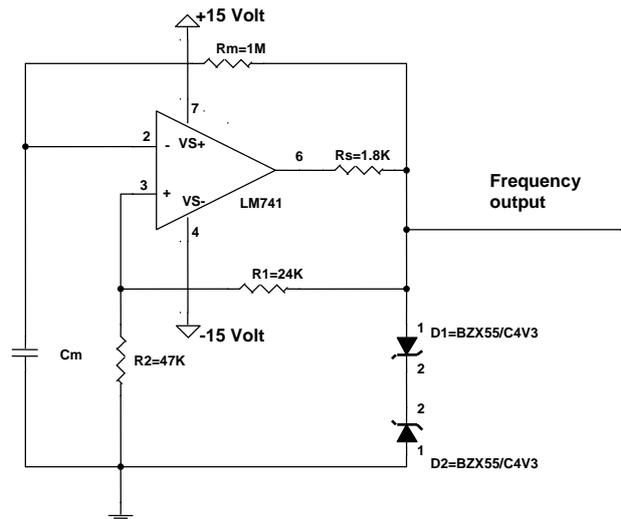


Figure 1.1

The frequency output of the oscillator in Figure 1.1 above can be described by the following equation:

$$f_{osc} = \frac{1}{2R_m C_m \ln(Q)}$$

$$Q = \frac{R_1 + 2R_2}{R_1}, \quad Q \leq 10, \quad 10 \text{ k}\Omega \leq R_2 \leq 100 \text{ k}\Omega$$

You can use the circuit for measuring either the capacitance  $C_m$  or the resistance  $R_m$ . The frequency output will be inversely proportional to the measured capacitance or resistance. To get a linear output from the detector circuit, the following method can be used:

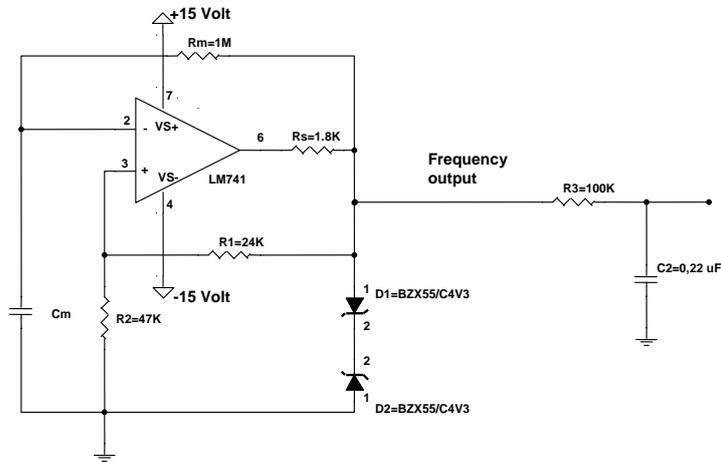


Figure 1.2

In Figure 1.2 above, a first order low pass filter has been added to the circuit output. The cut-off frequency of the filter must be chosen such that it is about 100 times lower than the lowest oscillator output. Taking a look at the transfer function of the simple RC filter:

$$H(\omega) = \frac{1}{1 + j\omega RC}$$

Assuming that frequency is much higher than the cut-off frequency, the

transfer function can then be written as 
$$H(\omega) = \frac{1}{j\omega RC}$$
.

The cut-off frequency of the output filter in Figure 1.2 is calculated as 
$$f_g = \frac{1}{2\pi \cdot R_3 \cdot C_2} \approx 7 Hz$$

The oscillator generates a square wave at its output, which means a spectrum of frequencies. The true rms value of this filtered spectrum can be measured at the detector output, and will then be directly proportional to  $C_m$  or  $R_m$ . Recall that the true rms value for a periodic signal

$x(t)$ , with period  $T$ , is defined as 
$$U_{TRMS} = \sqrt{\frac{1}{T} \int_0^T x^2(t) \cdot dt}$$
. The rms value can equally be

calculated in the frequency domain, 
$$U_{TRMS} = \sqrt{\sum_{k=0}^{\infty} X_{rms,k}^2}$$
.  $X_{rms,k}$  is the rms value of each frequency component in the Fourier series expansion of the periodic signal  $x(t)$ .

### 1.3 Capacitive sensor theory

A simple capacitive sensor can be created by running a wire-pair running up and down the inside of a plastic tube, see Figure 1.3. Such a sensor can be used to measure the level of a substance inside the detector.



Figure 1.3 – Cross-section of the sensor seen from the inside and the outside

The equation for a parallel-plate capacitor is:

$$C = \epsilon_r \epsilon_0 \frac{A}{a}$$

$A$  is the area of the plates, and  $a$  is the distance between them. Replacing the air-gap between the plates with some liquid or powder will change the relative dielectric constant  $\epsilon_r$ , thus changing the capacitance.

**Task 1.**

According to the criteria given above, design a capacitance-measuring device ranging from 80pF to 300pF. Use the circuit in Figure 1.2. Provide the instrument with two calibration curves, voltage vs. capacitance and frequency vs. capacitance. The Fluke multimeter can measure both true rms voltage and frequency.

**Task 2.**

The detector used in this experiment consists of a plastic tube with a wire pair running up and down along the inside of the tube. Explain how the behaviour of its capacitance will be similar to that of the parallel-plate capacitor described above. The wires inside the detector are not perfectly straight (look inside). What effect could this have?

Using the Philips RCL-meter, plot a calibration curve for capacitance vs. liquid level for the detector, see Figure 1.4, using a beaker of water given to you by your teacher.

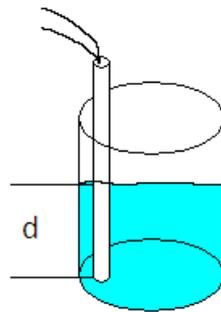


Figure 1.4

**CAUTION: TAKE CARE NOT TO SPILL WATER ON ANY OF THE ELECTRONICS**

**Task 3.**

Design a measuring device that gives an rms voltage on its output as a function of the liquid level.

Provide the instrument with a calibration curve.

## 2 Temperature measurements

### 2.1 Introduction

Measurement of temperature is important in several applications. In process industry for example, furnaces have to be stable in temperature within 0.1 °C in order to keep the tolerance for a specified process in acceptable accuracy. Thermocouple elements are used when the temperature is relatively high (exceeding 1300 °C for some types of element), where other measurement systems fail because of temperature stress. Thermocouples can also be used at very low temperatures. The disadvantage with thermocouple elements for absolute measurements is that one of the two electrodes has to be kept at a known temperature, i.e. reference electrode.

The temperature at the reference electrode must then be measured for example with a resistive sensor of standard type Pt 100. The material in the resistive sensor is platinum, and the resistance is 100 Ω at 0 °C.

Remote measurements where the instrument has no physical contact with the object are often done for safety reasons. One important example is to measure the temperature in high power, high voltage circuits. The advantage of remote measuring is that the circuit is operating at normal voltage and current so that unacceptable contact resistance can be detected due to increase in temperature.

### 2.2 Objective

To be oriented in some common ways to measure temperature.

### 2.3 Measurement with thermocouple element

A simple way to keep the reference electrode at known constant temperature is by using melting ice.

**Task 1**

Measure the voltage emf in a thermocouple element by keeping its reference electrode in melting ice and its other electrode in boiling water. Compare with expected emf from Table 2.1. The emf is relatively small (mV), so it is a good idea to use an instrumentation amplifier with high input impedance. See the circuit diagram in Figure 2.1 and the data sheet for the instrumentation amplifier in Appendix. You will need to connect the output terminals of the thermocouple element to the input of the instrumentation amplifier circuit. Connect a digital voltage meter to the amplifier output, and measure the generated emf. The signal is amplified by a factor of 106. What is the temperature of the boiling water?

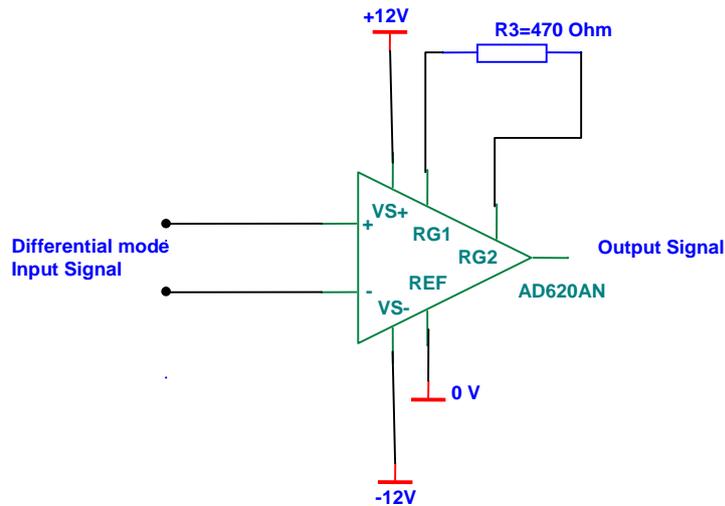


Figure 2.1

## 2.4 Resistive sensor (Pt 100) for measuring temperature

In this case the reference electrode in a thermocouple is held at room temperature. A resistive sensor, Pt100, is used to measure the room temperature. To avoid error caused by the resistivity in the cables, the Pt100 sensor is measured using the four-point method. A simple circuit, see Figure 2.2, feeds the sensor with current on separate wires, and measures the voltage-drop directly on the device. The amplification from the instrumentation amplifier is 106 times.

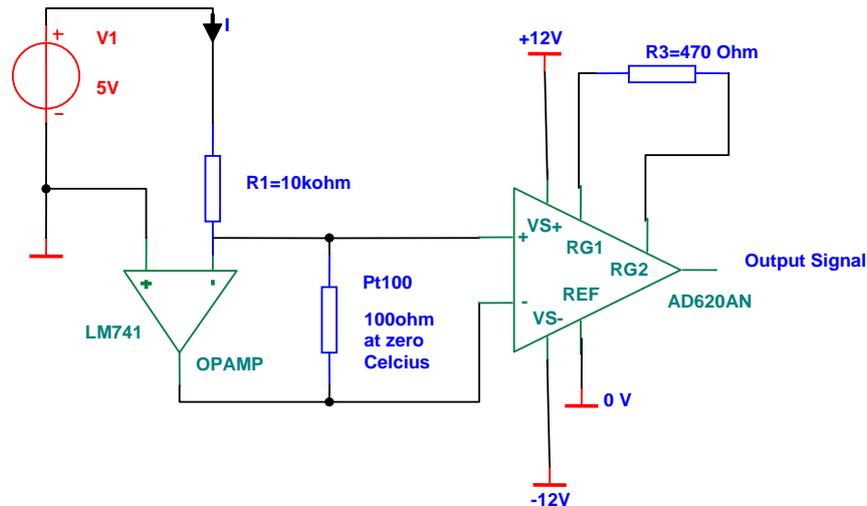


Figure 2.2

The opamp circuit gives a constant current through the resistive sensor. This current  $I$ , flowing through the Pt100 element and  $R1$  equals  $V1/R1$ .

### Task 2

Measure the room temperature with the circuit in Figure 2.2 and the Pt 100 sensor. Compare with an ordinary digital thermometer. Explain why the circuit only measures the resistance in the Pt 100 sensor, and not any contribution in the connection cables.

### Task 3

Measure the voltage emf in a thermocouple element by keeping the reference electrode at room temperature, and the other electrode in boiling water.

Measure also the voltage emf with the reference electrode in melting ice and the other at room temperature. The room temperature is measured with the Pt 100 sensor close to the thermocouple element electrode. The resistance-temperature relationship is shown in Table 2.1. If a value is missing in Table 2.1, do interpolation in-between.

Sum the emf and compare with the emf in task 1. They should be equal and illustrate the additive properties of the thermocouple element.

Temperature °C	Resistance Pt 100 $\Omega$	Emf type k mV
-50	80.31	-1.889
-40	84.27	-1.527
-30	88.22	-1.156
-20	92.16	-0.778
-10	96.09	-0.392
0	100	0
10	103.90	0.397
20	107.79	0.798
30	111.67	1.203
40	115.54	1.612
50	119.40	2.023
60	123.24	2.436
70	127.08	2.851
80	130.90	3.267
90	134.71	3.682
100	138.51	4.096
110	142.29	4.509
120	146.07	4.920
130	149.83	5.328
140	153.58	5.735
150	157.33	6.138

Table 2.1

### 3 Signal processing and data analysis using LabVIEW

#### 3.1 Objective

These experiments are developed with the aim of introducing a software for instrumentation, signal processing and data analysis. The preferred software for this is LabVIEW from National Instruments.

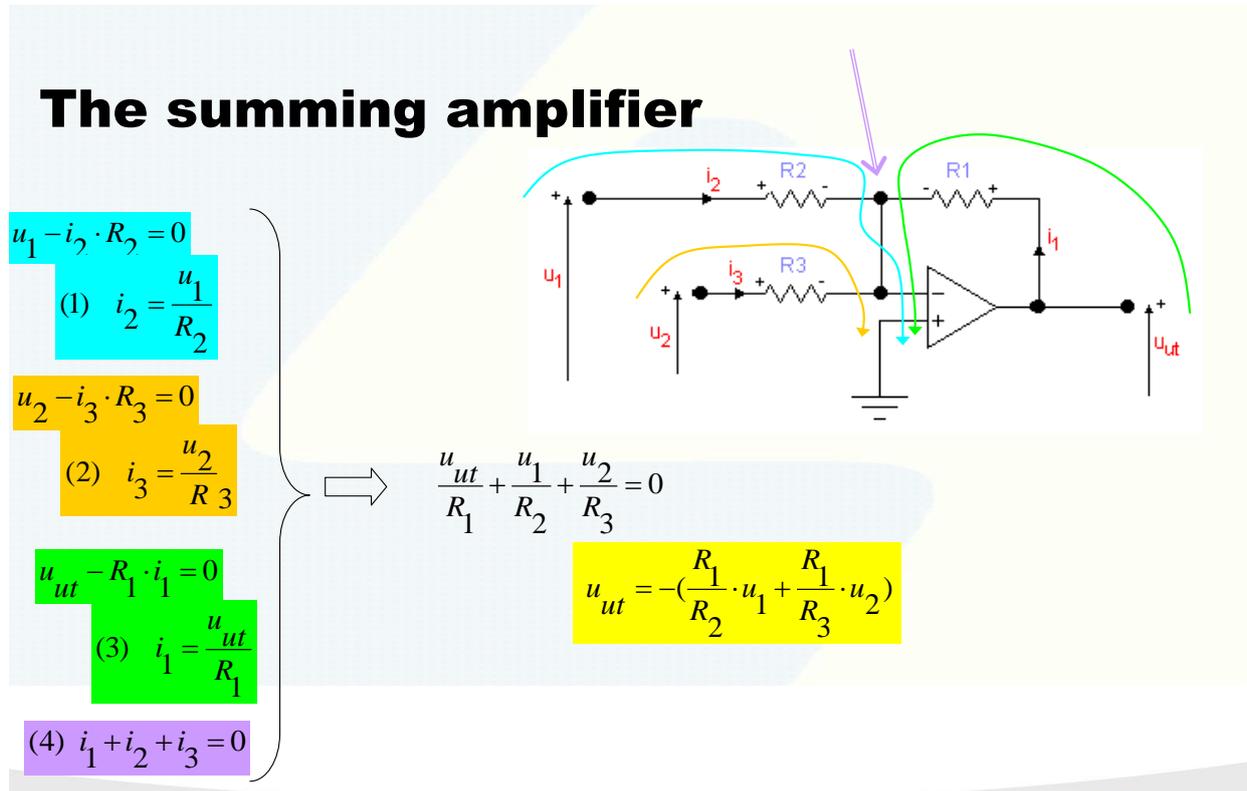


Figure 3.1. Summing amplifier.



Figure 3.2. DAC-ADC unit to be used with LabVIEW.

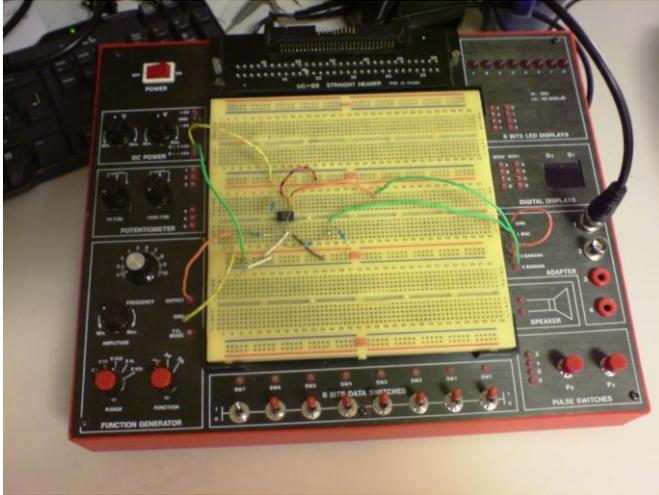


Figure 3.3. Experiment lab board for electronic circuits.



Figure 3.4. HP 33120 function generator.

### 3.2 Preparations

Connect a summing amplifier circuit according to Figure 3.1 using operational amplifier CA3140. Use  $10\text{ k}\Omega$  for  $R_1$  to  $R_3$ . Use the electronic lab equipment shown in Figure 3.3. This unit has both built in power supplies as well as a signal generator. Use that signal generator to feed  $U_1$  with a sine wave signal having an amplitude of about  $0.1\text{ V}_{pp}$  and a frequency of about  $1\text{ kHz}$ . Connect an additional function generator, see Figure 3.4, to input  $U_2$ . This function generator must be set up to generate noise with an amplitude of about  $2\text{ V}_{pp}$ .

#### Task 1

You are going to study a sine wave signal having very low Signal to Noise Ratio (SNR), thus completely polluted with additive noise. Apply FFT amplitude spectrum analysis in order to distinguish and detect the sine wave signal (in logarithmic scale). Study the use of additional mean value calculation of every data set of FFT spectrum and how it affects the visibility of a present signal. The FFT spectrum and modules for displaying can be accessed within the LabVIEW environment. Also study the use of windowing functions. Does using a window function help detecting weak signals in a noisy background? Figure 3.5 shows an example of a LabVIEW graph for the FFT spectrum analysis using both window and no window function as well as an oscilloscope display.

**Task 2**

Do the same experiment as in Task 1, but using autocorrelation analysis.

**Task 3**

Change the external function generator shown in Figure 3.4 to generate a sine wave with the amplitude of  $2 V_{pp}$ . Also adjust the function generator built in the experimental electronic circuit lab, see Figure 3.3, to have amplitude of  $2 V_{pp}$ . Use LabVIEW for FFT amplitude spectrum analysis. Study the case when the frequencies of the two sine waves are close to being equal and for different windowing functions. Does using a window function help if you need to see two signals with almost equal frequency?

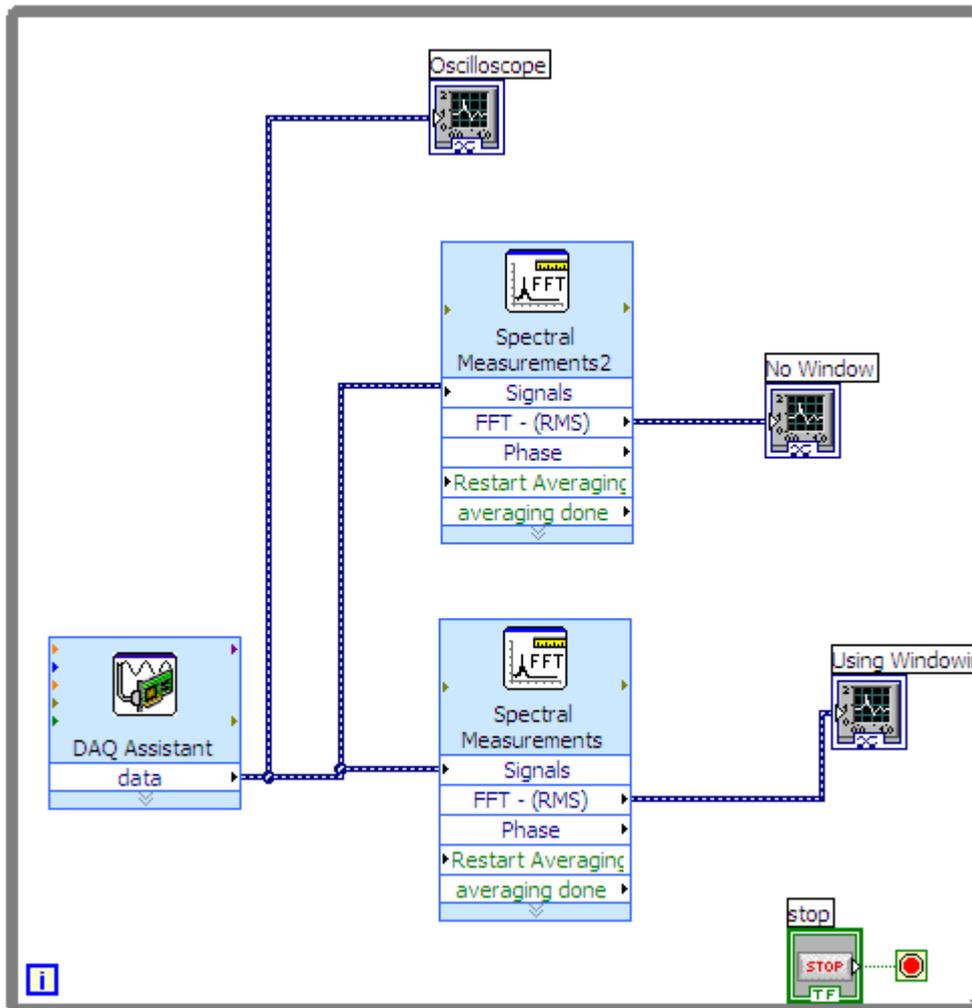


Figure 3.5. LabVIEW graph for FFT spectrum analysis.

## 4 Load measurements

### 4.1 Introduction

A load cell can be created using strain gauges. A resistor exposed to stretch will increase its resistance, and a resistor exposed to compression will decrease its resistance.

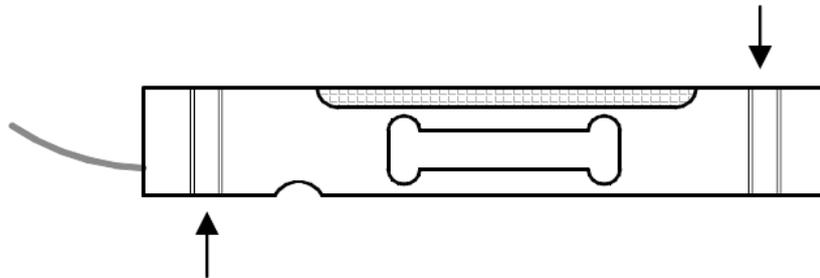


Figure 4.1 – single point load cell

This fact can be used to connect the resistors in a bridge, and the load cell you'll be using has one of these bridges built-in. Its configuration is as follows:

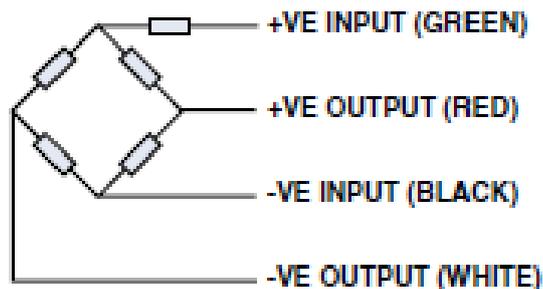


Figure 4.2

It can easily be shown that the detector voltage on the output is proportional to the resistance changes. The bridge can be driven with either DC or AC. For the latter the detector output will be an amplitude modulated carrier voltage.

### 4.2 Objective

In this experiment you will learn how strain gauges can be used to measure a load with a single point load cell, see Figure 4.1. You will learn how a bridge connected sensor can be driven with a carrier frequency and how LabVIEW can be used for simple signal processing and displaying of measurements.

### 4.3 The amplitude modulated bridge

As input for the bridge shown in Figure 4.2, use as carrier frequency consisting of a sinus wave having amplitude of about 10 Volts and a frequency of about 1 kHz. An AD620 instrumentation amplifier is connected to the bridge output having an amplification factor of about 100, see Figure 4.3. The ADC input is then connected to the amplifier output for signal processing and displaying in the computer using LabVIEW.

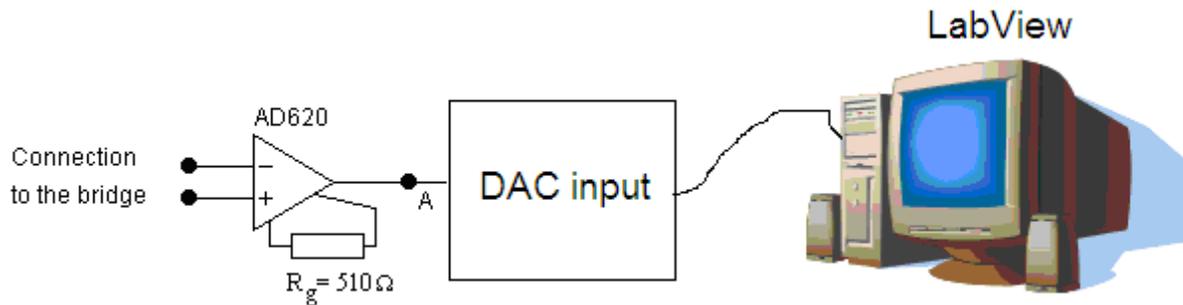


Figure 4.3

#### Task 1.

Design a modulated detector circuit according to Figure 4.3 using the AD620 instrumentation amplifier. Your teacher will supply you with a single point load cell and some weights. Design a LabVIEW program that samples the detector signal at 10 kHz. Connect a digital band-pass filter within LabVIEW having its center frequency equal to the bridge carrier frequency. Use an rms voltage detector after the filter, and use scaling to calibrate a display that will show the number of weights placed on the load cell.

**CAUTION: THE LOAD CELL ONLY HANDLES UP TO 3kg.**

#### Task 2.

Imagine that the wires between the detector circuit and the bridge on the load cell are located in a very noisy industrial environment. 50 Hz noise coming from an adjacent 500 kW motor is interfering with the measured signal. This can be simulated within the LabVIEW environment by adding a simulated 50 Hz voltage source.

How much is the 50 Hz noise attenuated compared to the bridge carrier signal.

What is the benefit of driving the bridge with a carrier frequency rather than a DC voltage?

LabVIEW programs and display panels can easily be screen captured by pressing **Ctrl + PrtSc**.

## 5 Noise and noise reduction

### 5.1 Objective

Measurement systems are often exposed to noise from their environment, and your own measuring devices can also act as noise for other measurement systems. If you are aware of this when designing a measurement system, you can take precautions to reduce the impact of noise on your measurements, and reduce the amount of noise emitted by your system. In this experiment you will look at some kinds of induced noise, and get familiar with methods used to reduce this noise.

You will be using two lab boards; one will be acting as a transmitter, and the other as a receiver. The two boards will be connected by a cable provided by your teacher. The cable has a number of internal wires and a shield (black wire on the connector). You will be using two function generators; the one built into your lab board, see Figure 5.1, and an external one, see Figure 5.2. Take care not to break the connectors on your cable.

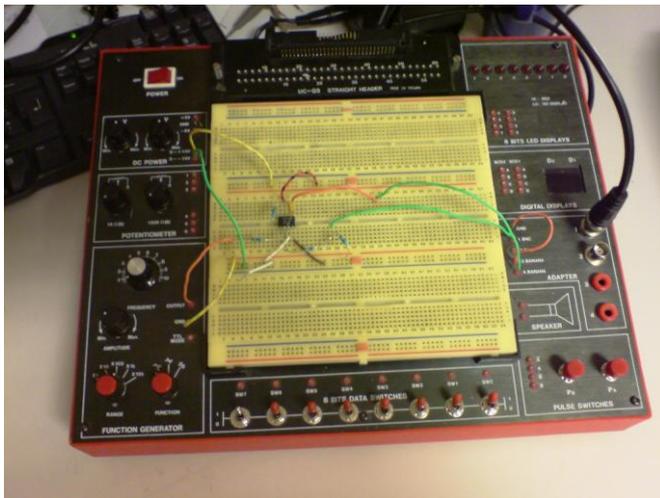


Figure 5.1. Experiment lab board for electronic circuits.

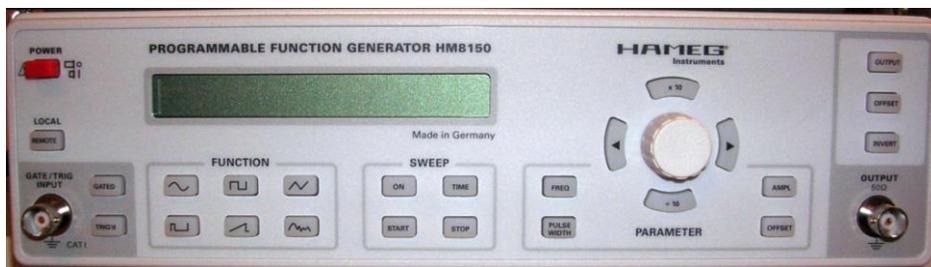


Figure 5.2. Hameg HM8150 Function Generator.

**Task 1**

On the transmitter end, use the onboard function generator to generate a sine wave with approximately  $100\text{ mV}_{pp}$  and  $15\text{ kHz}$ . Connect this signal to one of the cable wires on the transmitter end. On the receiver end, connect the same wire to local ground over a  $100\Omega$  Resistor. Use the oscilloscope to display the voltage over this load.

Different locations may have different ground potentials. Is there a difference in ground potential between your transmitter and receiver? What effect would a difference in ground potential have on measured signals?

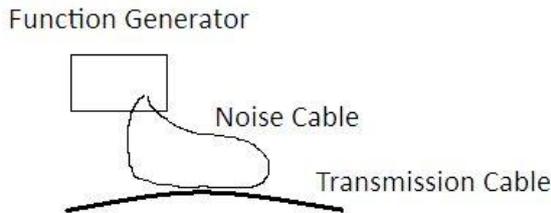


Figure 5.3a

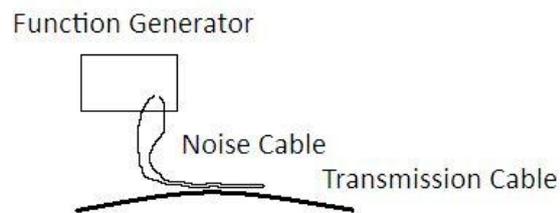
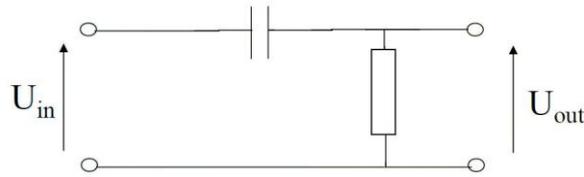


Figure 5.3b

Assemble a cable loop by using two long banana plug cables to connect two BNC/Banana plug adapters. Terminate one of the BNC connectors with a  $50\Omega$  resistance, and connect the other BNC connector to your external function generator as shown in Figure 5.3a, creating a loop for current to flow through. Set the external function generator to output a  $5\text{V}$   $200\text{ kHz}$  sine wave. This "noise cable" will now emit noise that can interfere with signals passing through your transmission cable. Place one side of the loop next to your transmission cable, and observe any changes to your measured signal.

Rearrange your loop cable as in Figure 5.3b, so that two opposite sides of the loop are next to each other. What happens to the induced noise? How can you take advantage of this when routing cables?

Go back to only having one side of the loop next to your transmission cable. Connect the shield on your cable to ground on one end, and observe the results. Next, connect the shield to ground on both ends. What happens to the induced noise? Can you draw any conclusions from this?

**Figure 5.4 – High Pass Filter**

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

**Equation 5.1 – Cutoff frequency for a first order RC filter**

*Your teacher will provide you with a 50 Hz power supply and a coil. When the coil is supplied with power, it will emit an EM field (note that the coil grows hot when it is supplied with power, so don't keep it powered up for prolonged periods). Loop your signal cable around the coil a couple of times, and see what effect this EM field has on your signal.*

*The grounded shield will already have reduced this 50 Hz noise somewhat. With the help of Equation 5.1, design a passive first order RC high pass filter, see Figure 5.4, that will reduce the noise further. Did the situation improve?*

**Task 2**

Set the onboard function generator to output a  $100\text{ mV}_{pp}$   $15\text{ kHz}$  sine wave, and the external function generator to output a  $5\text{ V}$   $50\text{ kHz}$  sine wave signal. Connect these signals to one cable wire each on the transmitter side. Connect another wire on the transmission cable to ground - this wire will be used on the receiver end to provide ground for both signals. On the receiver side, connect both signal wires to the ground wire over one  $100\ \Omega$  Resistor each, see Figure 5.6. Both signals now share one common ground, and thus also share a common impedance. Measure the  $15\text{ kHz}$  signal by using one oscillator probe on each side of its load resistor, and letting the oscilloscope calculate the difference between the two measured voltages. Observe the effect the signals have on each other.

To avoid the effect of having a shared impedance, re-design your connections so that each signal uses its own ground wire (i.e. one wire pair per signal) see Figure 5.7. Did the situation improve?

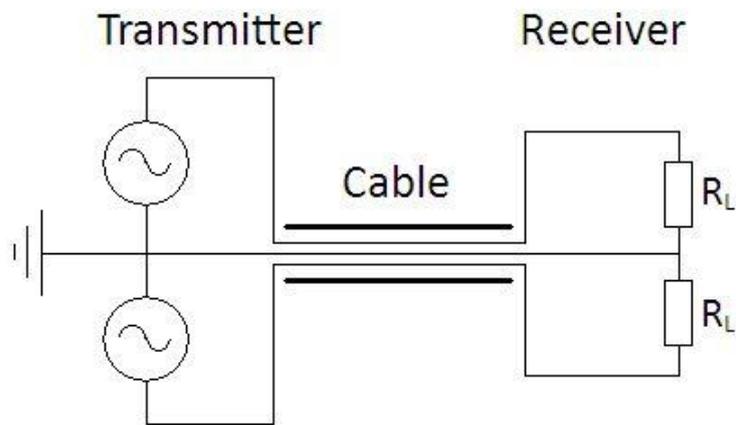


Figure 5.6

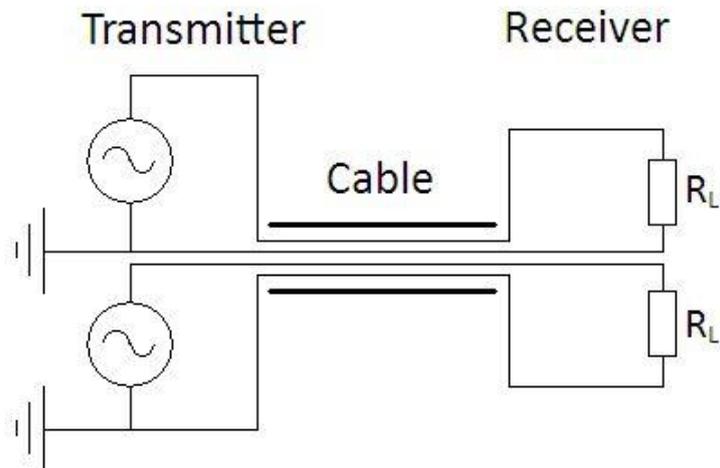
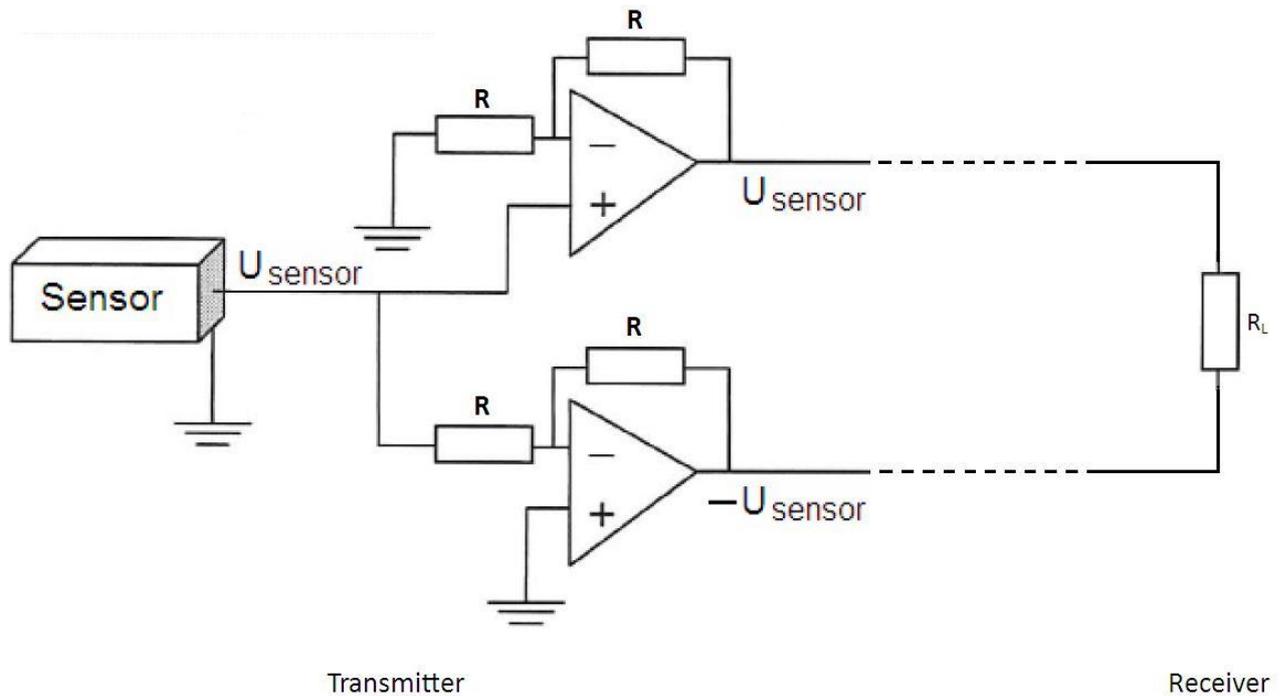


Figure 5.7

**Task 3**

It is often desirable to use differential ended signaling over two wires, since this generally gives better noise characteristics than single-ended signaling over one wire. One way to convert a single ended sensor into a differential ended sensor is to combine an inverting and a non-inverting amplifier, as shown in Figure 5.8. Design such a device, using LM741 Op amps and  $R = 10\text{ k}\Omega$ . Use this device to transmit the output of the onboard function generator over your transmission cable as a differential ended signal. On the receiver side, measure the signal over a  $100\ \Omega$  load resistor. Explain any differences on the signal compared to single ended signaling.



**Figure 5.8**

## 6 Instructions for reports and oral presentations

- **All** students (ET013G and ET044G) must prepare a 15 minute oral presentation for each lab. These presentations must have a disposition corresponding to a full technical report. This means that you need to give an introduction, define the problem, present methods and results, as well as also analyse the results, draw conclusions, answer the questions in the labs, and point out possible alternative methods. A seminar will be held at the end of the course, where all lab groups will give their oral presentations. All lab group members must participate actively in the presentations. The oral presentations must be based on PowerPoint slides. The first slide must have the names of all lab group members written on it. The PowerPoint slides are to be sent to the lab supervisors before the presentation. All lab groups will present one lab out of five possible; which one will be decided by the teacher at the day of the seminar and at the last minute. This means that you need to be prepared to present any of the five labs.
- If you are studying ET013G, you must **also** prepare a written report for each lab, with the same disposition as is described for the presentations above. Each report should be submitted to the lab supervisors within a week of the corresponding lab session. For example, the report for the 1<sup>st</sup> lab should be submitted within a week of the 1<sup>st</sup> lab session, the report for the 2<sup>nd</sup> lab within a week of the 2<sup>nd</sup> lab session, and so on.