Contents

1 Chapter 8 - Sensor interface and bus system

1.1 What is cross-sensitivity? Give two compensation techniques cross-sensitivity.

|| Book reference: "8.3.2 Cross-sensitivities" (pp. 403-406)

When a sensor is sensitive to an undesirable parameter we say this sensor as a cross-sensitivity to that parameter.

Solutions:

- Design a sensor in such a way that some parts of the sensor have a temperature (or any other parameter) coefficient which is opposite to other parts. Eg. Varying resistor with positive temperature coefficient in series with varying resistor with negative temperature coefficient.
- Add a sensor measuring the undesirable parameter. Correct the output of the main sensor using the measure of the undesired parameter. Eg. Pressure sensors are often temperature dependent, add a temperature sensor and compensate the measured the pressure.
- Still another technique would be using a differential measurement scheme. Eg. a Wheatstone bridge

Other examples: Switching current and voltage contacts in a Hall plate (same as electronic instrumentation)

1.2 Give a block-diagram of a sensor bus system, with single and multi sensor modules.

|| Book reference: "8.6.3 Bus systems" (pp. 424-426)

1.3 Draw a Wheatstone-bridge for pressure measurement with all four resistors used as a sensor give the expression of for the output signal. Each resistor has a temperature coefficient of resistance and also for mechanical stress. Give the expression for the output signal for an elevated temperature. Is there a difference if the bridge is powered by constant voltage or constant current? Why?

$$V_O = V_{EX} \cdot \frac{\Delta R}{R} \tag{1}$$

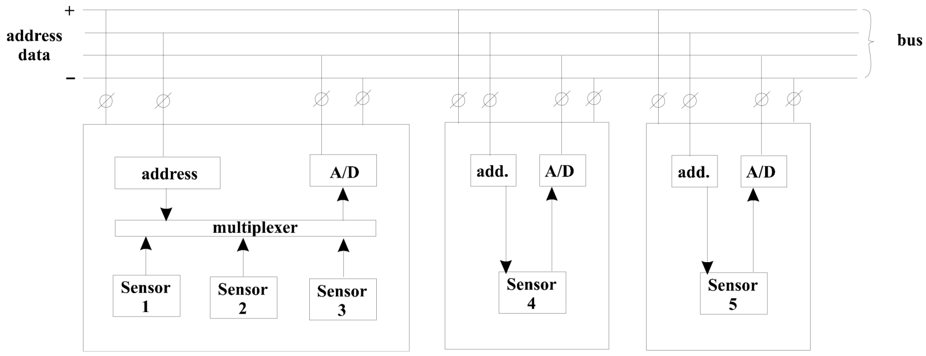

Figure 1: Digital sensor bus interface structure

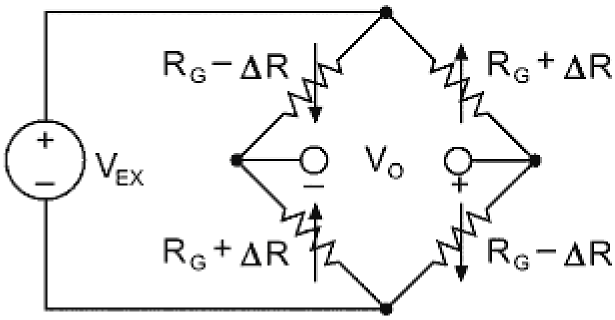

Figure 2: Wheatstone bridge - 4 varying resistors

If the temperature coefficient is the same for all sensors then they will be no change to the output. If two are positive and two are negative the change in output voltage is equal to (1).

If the bridge is supplied by a current source. The current is equally divided in each branch ($R - \Delta R \ + \ R + \Delta R = R + \Delta R \ + \ R - \Delta R$). And the ouptut voltage is equal to:

$$V_O = \frac{I}{2}(R - \Delta R) \ - \ \frac{I}{2}(R + \Delta R) = -I\Delta R$$

1.3.1 Why is a Wheatstone bridge used fro pressure measurement? Draw a bridge with one, two and four sensing resistors and give formula for the output signal. Each resistor is sensitive to temperature sensitive. How can we make this cross sensitivity as small as possible?

A Wheatstone bridge is differential measurement. It is used because it has a high sensitivity so it can be very accurate.

1 varying resistance $V_O = V_{in} \cdot \frac{\Delta R}{4R}$

2 varying resistance $V_O = V_{in} \cdot \frac{\Delta R}{2R}$

4 varying resistance $V_O = V_{in}.\frac{\Delta R}{R}$

1.3.2 Compare the output and temperature coefficient of a Wheatstone bridge based piezoresistive pressure sensor, with; a) 1 resistor as sensor, b) 2 resistors as sensor and c) all 4 resistors as sensor.

1.3.3 How can temperature sensitivity be reduced in a pressure sensor based on piezoresistors?

Use a balanced differential measurement method. Eg. Wheatstone bridge.

1.4 How does the "sensitivity variation method" work to reduce offset? In which circumstances does this not bring the offset to zero?

|| Book reference: "8.3.1.1 Sensitivity-variation offset-reduction method" (pp. 401-403)

$$V_{out} = S_{entivity}M_{easure} + O_{ffset}$$

By applying a modification to the sensor (thus to the sensitivity). Two output values can me found for the same measure. This allows us to calculate the offset. If we know the offset we can simply subtract it to the value reported by the sensor.

$$\begin{cases} V_1 = S_1 M + O \\ V_2 = S_2 M + O \end{cases} \iff \begin{cases} M = \frac{V_2 - V_1}{S_2 - S_1} \\ O = \frac{S_2 V_1 - S_1 V_2}{S_2 - S_1} \end{cases}$$

These modifications could be a change in temperature or in the surrounding magnetic field, etc.

However this technique only works if the modification we apply to the sensor does not affect the offset.

1.5 What is the basic principle of a flip-flop sensor? What are the advantages and disadvantages of this technique?

|| Book reference: "8.4.2.3 Stochastic analogue-to-digital converters" (pp. 415-417)

An equally distributed number of '1' and '0' can be generated at the output of a flip-flop circuit by switching on and off the supply voltage the circuit. This is due to the noise in the flip-flop circuit components. However, if an asymmetry is introduced in the circuit this distribution will no longer be equally distributed. By counting the number of '1' and '0' it is possible to measure the asymmetry in the circuit. Figure 3 shows two sensors based on the flip-flop circuit.

A flip-flop sensor as the advantage of being highly accurate and immune to noise (binary output). The output of the flip-flop sensor is easy to interpret

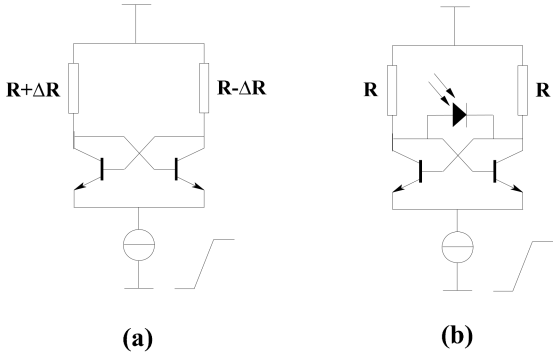

Figure 3: (a) Pressure sensitive flip-flop, (b) light-sensitive flip-flop

(count pulses). Flip-flop circuits are small so they can easily be arranged in arrays.

A disadvantage of the flip-flop circuit is that the input signal must be stationary for an amount of time that is long enough to produce enough supply voltage pulses to generate an equally distributed number of '1' and '0' at rest.

1.6 How can a ring-oscillator be used as a sensor? Give two examples.

No reference in book

A ring oscillator is a device composed of an odd number of NOT gates. The output is fed back to the input to create an oscillating circuit (period is twice – full cycle – the delay of each gate gate).

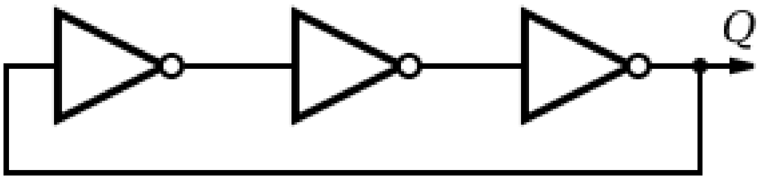

Figure 4: 3-inverter ring oscillator whose output frequency is 1/(6xinverter delay

Temperature If the NOT gates are built using CMOS technology a linear dependency is introduced between the oscillation frequency and the bias current. If the bias current is temperature dependant, then oscillation frequency and temperature are dependant. [source: S. Suman and B.P. Singh, "Design of Temperature Sensor Using Ring Oscillator", *International Journal of Scientific & Engineering Research*, Vol.3:5, 2012]

Pressure By building a CMOS ring oscillator which includes a MEMS pressure sensing capacitance it is possible to build a pressure sensitive ring oscillator. This is illustrated in figure 5. [source: Ching-Liang Dai, Po-Wei

Lu , Chienliu Chang and Cheng-Yang Liu, "Capacitive Micro Pressure Sensor Integrated with a Ring Oscillator Circuit on Chip", *Sensors*, pp. 10158-10170, Sept 2009]

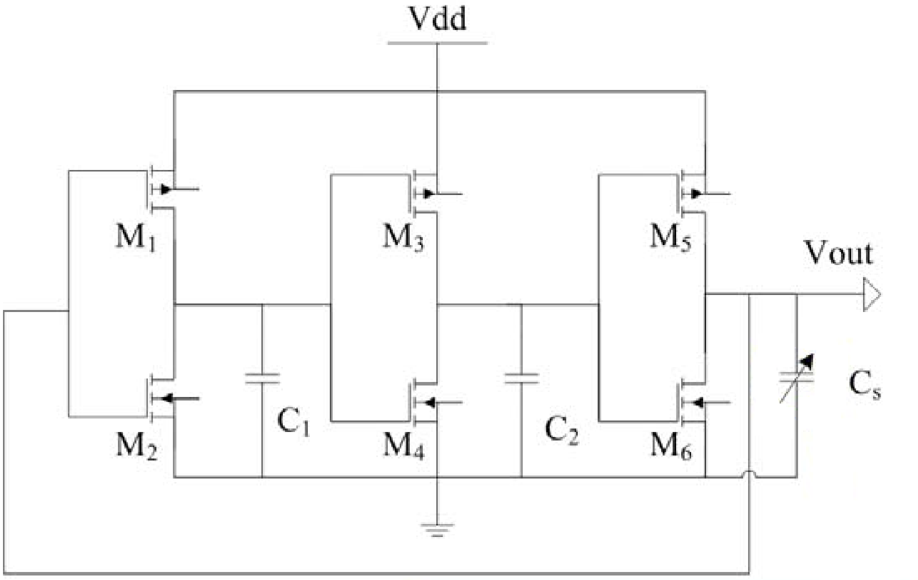

Figure 5: Pressure sensing ring oscillator

1.7 A sensor signal can be converted into a frequency. Give three methods to generate a frequency output from a sensor signal.

1. A voltage controlled oscillator. Using a switch to charge and discharge a variable capacitor. This gives a triangular type wave, which can be converted into a square wave using a comparator.

2. A ring oscillator - a ring oscillator contains an odd number of inverters with a feedback loop. The oscillator will give a frequency output with a frequency determined by the number of inverters and the switching time of each inverter. If we can make the switching time a function of the measurand, we have a frequency output sensor. One example is the pressure sensor using CMOS. If the inverters are stressed, the switching time is changed due to the piezoresistive effect in the channel.

3. A SAW device. Surface acoustic waves are sent over the surface of the device using a piezoelectric material. The time wave takes to travel from the sender to the receiver can be made to be a function of the measurand. For example, for measuring liquid density, where a more dense liquid will slow down the wave's progress. If we feed this output back to the input, we can generate a frequency, which is a function of the speed of the wave over the surface

2 Chapter 1 - Development of actuators

2.1 How do you protect against: over-current, over-voltage and over-temperature? Give for each a simple example circuit

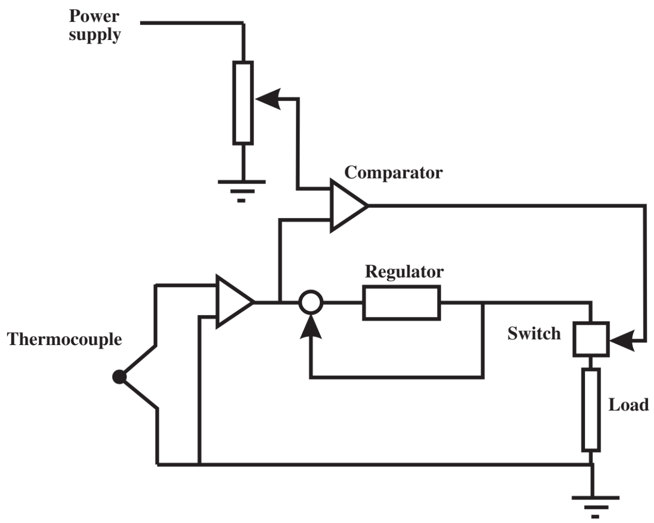

Figure 6: Circuit for over-temperature protection - simple negative feedback control loop

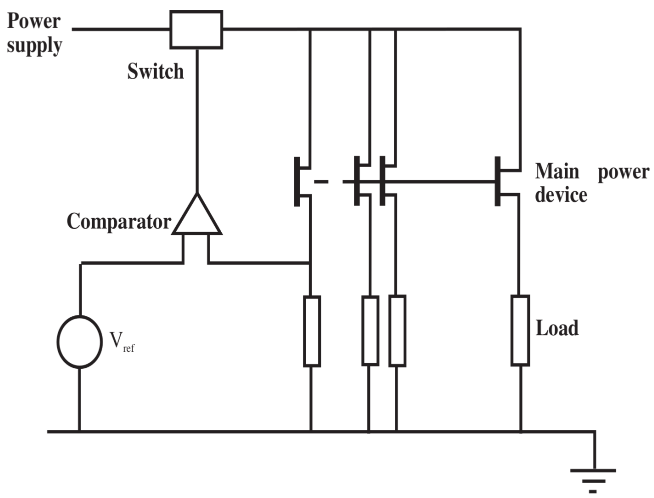

Figure 7: Circuit for over-current protection

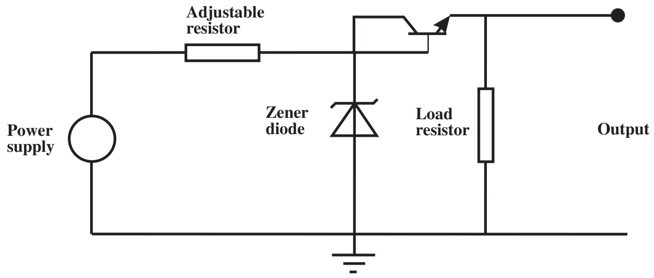

Figure 8: Circuit for over-voltage protection

2.2 Describe how thermal actuation can be used in the macro scale. For the solution you have chosen, can this be scaled down to micro-level?

The steam engine is an example of thermal actuation. High pressure steam enters a chamber and pushes a piston which expels exhaust air. Then the process is reversed by exchanging the exhaust and high pressure steam pipes. It is not really possible to scale a steam engine down to the micro-level.

2.3 Describe the structure and working principle of AC and DC electromotors

DC A coil is placed in a magnetic field. The coil is supplied by DC current $\rightarrow$ force makes coil align magnetic field. Then the direction of the current is reversed and a new half-cycle begins.

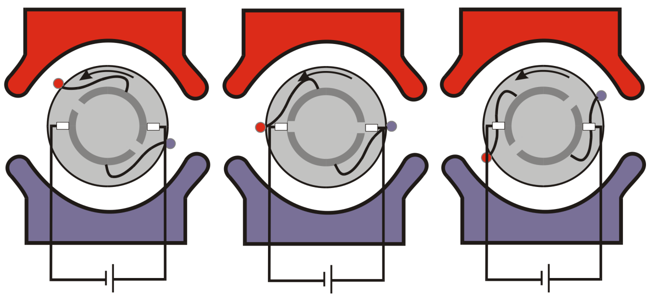

Figure 9: DC motor

AC Alternating current produces a rotating magnetic field in stator (eg. 3 phase). Rotor bars receives varying magnetic Field $\rightarrow$ induced current in rotor $\rightarrow$ force on the rotor.

2.4 All six signal domains can be used to generate mechanical energy. Describe for all 6 how this can be done, with examples of actuators.

mechanical wind mill

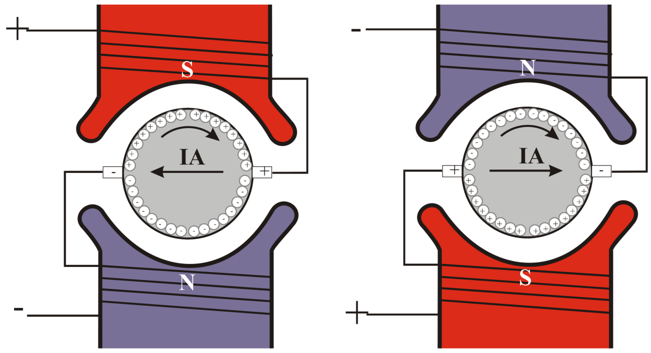

Figure 10: AC motor

thermal steam engine

radiation solar panel connected to DC motor

magnetic ??? DC motor ???

chemical battery connected to DC motor

electric DC motor

2.5 Describe the cycle of a petrol motor.

1. Intake: the piston moves downward, drawing a fresh charge of vaporized fuel/air mixture.
2. Compression: Flywheel momentum drives the piston upward, compressing the fuel/air mixture.
3. Power: At the top of the compression stroke, the spark plug fires, igniting the compressed fuel. As the fuel burns it expands, driving the piston downward.
4. Exhaust: The upward stroke of the piston drives the exhausted fuel out of the cylinder.

2.6 Describe the main differences between hydraulic and pneumatic systems. How do these properties determine the applications where they are used?

- Hydraulic uses an incompressible fluid to transfer movement whereas pneumatic uses a compressible gas to transfer force.
- Hydraulic systems are bulky, pneumatic are usually light and handheld.
- Hydraulic systems are slow, pneumatic are fast.
- Hydraulic system force 10^8 N, pneumatic 10^4 N

Applications: Hydraulic: heavy lifting, aircraft/ship controls
Pneumatic: hand held tools, such as drills

2.7 What is a linear electric motor. How does this compare with conventional electric motors in terms of structure and working principle? What are the advantages with this technique for the transport industry.

The basic principle of a linear motor is as a conventianol one. It can be considered as motor which has been rolled out. Although invented in the 19th century it was not until the 1950s that a commercial application was found. More recently the linear motor has been applied to rail transport. Since there is no physical contact between the train and the ground considerably higher speeds than conventional trains can be achieved.