Exercise 01: Safety in Automation and Static Characteristics of Measurements

Task 1.1: HARA for a 4-Corner Air Suspension System (4CAS)

A 4CAS system is used to maintain/control a vehicle's height during different operational conditions. These conditions gives rise to a number of hazards that could possibly lead to fatal results. Perform a Hazard Analysis and Risk Assessment for this mechatronic system and design system-level safety goals.

System Description:

- 4 pneumatic air springs, one at each corner of the vehicle.
- Each corner has a height sensor and a valve.
- ECU processes height data and control valves.
- Driver can select ride modes (Comfort, Eco, Sport, Off-road).
- ECU maintains level height during all conditions.

1.1.1 Identify different Operational Situations considering the common operating modes given in the system description.

1.1.2 Identify the potential hazards that could arise from pneumatic, mechanical or E/E subsystems.

1.1.3 Combine the hazards and operational situations to define the Hazardous Events.

1.1.4 Perform a Risk Assessment based on the Severity (S), Exposure (E) and Controllability (C) using ISO 26262 Framework. Also derive ASIL (Automotive Safety Integrity Level).

1.1.5 Derive Mechatronics Safety Goals.

Task 1.2: Measurement Error and Accuracy

A pressure gauge with a measurement range of 0 - 10 bar has a quoted inaccuracy of 1.0% of the full-scale reading.

1.2.1 What is the maximum measurement error expected for this instrument?

1.2.2 What is the likely measurement error expressed as a percentage of the output reading if this pressure gauge is measuring a pressure of 1 bar?

Task 1.3: Measurement Precision

The width of a room is measured 10 times by an ultrasonic sensor and the following measurements are obtained (in meters):

$$3.521, 3.539, 3.538, 3.536, 3.525, 3.522, 3.534, 3.523, 3.527, 3.529$$

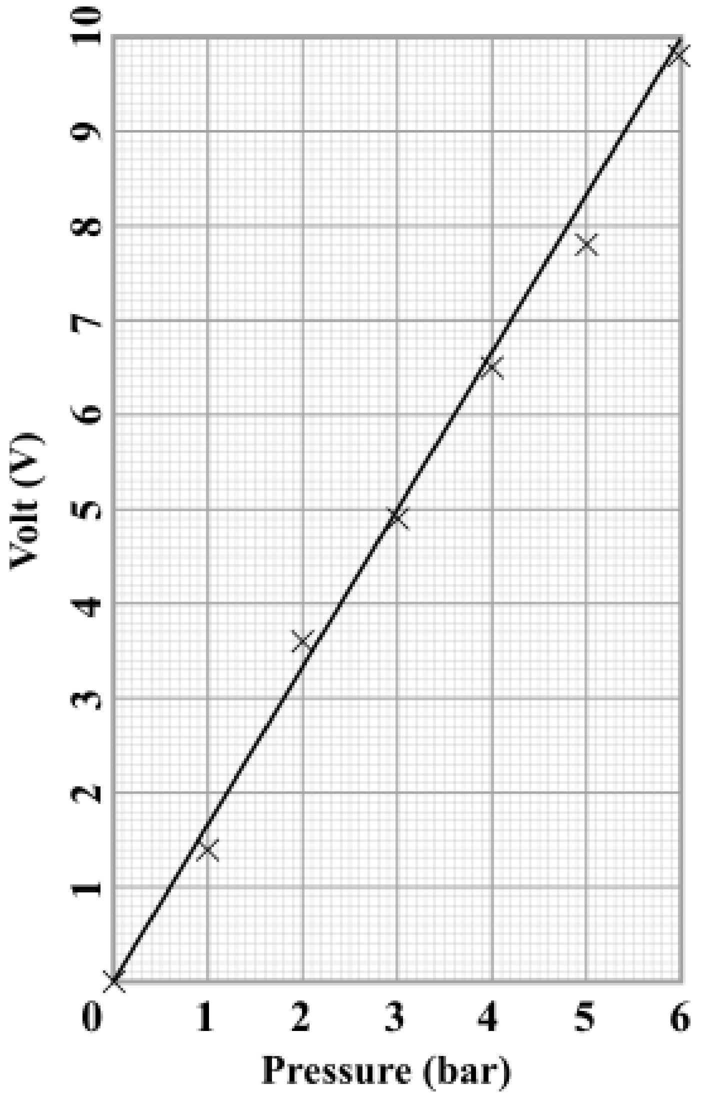
The width of the same room is then measured by a calibrated steel tape that gives a reading of 3.520 m, which can be taken as the correct value for the width of the room.

1.3.1 What is the measurement precision of the ultrasonic sensor?

1.3.2 What is the maximum measurement inaccuracy of the ultrasonic sensor?

Task 1.4: Linearity

Suppose the instrument characteristic shown in figure below is that of a pressure sensor, in which the input units are pressure in bars from 1 to 6 bar, and the output units are expressed in volts from 1 to 10 V.



1.4.1 What is the maximum nonlinearity expressed as a percentage of the full-scale deflection?

1.4.2 What is the resolution of the sensor as determined by the instrument characteristic given?

Task 1.5: Sensitivity

The following resistance values of a platinum resistance thermometer were measured at a range of temperatures. Determine the measurement sensitivity of the instrument in ohms per degree Celsius ($\frac{\Omega}{°\mathrm{C}}$).

Table 1.5.1: Measured resistance values of a platinum resistance thermometer.

Resistance (Ω)	**Temperature** (°C)
307	200
314	230
321	260
328	290

1.5.1 Determine the measurement sensitivity of the instrument.

Task 1.6: Zero Drift

This table shows the output measurements of a voltmeter under two sets of conditions:

1. use in an environment kept at 20 °C, which is the temperature at which it was calibrated; and
2. use in an environment at 50 °C.

Table 1.6.1: Voltmeter readings at different ambient temperatures.

Input	**Reading at** 20 °C	**Reading at** 50 °C
1	10.2	10.5
2	20.3	20.6
3	30.7	31.0
4	40.8	41.1

1.6.1 Determine the zero drift and the zero drift coefficient.

Exercise 02: Sensors

Task 2.1: Piezoelectric accelerometer under shock + drift

You're designing a 10 g full-scale accelerometer for impact testing using a PZT stack in the longitudinal mode (use d_{33} = 593 pC/N). The proof mass is m = 5 g. The shock is a half-sine a(t) = a_{pk} $\sin(\pi t/T)$ with a_{pk} = 500 m/s^2, T = 4 ms. The ceramic disk has active area A = 100 mm^2, thickness t = 0.5 mm, relative permittivity ε_r = 1500. Assume quasi-static force transfer F(t) = m a(t) and a charge amplifier with C_f = 100 pF, ideal op-amp.

2.1.1 Compute the sensor charge $Q(t)$ and amplifier output $v_o(t)$.

2.1.2 Estimate the sensor capacitance C_s and discuss how C_s versus C_f affects the scale factor and low-frequency droop.

2.1.3 If the device warms by +40°C, qualitatively discuss the expected sensitivity shift and explain why a constant force cannot be measured indefinitely with a piezoelectric sensor.

Task 2.2: Strain-gauge bridge

A steel cantilever (E = 210 GPa) carries a tip load that produces surface strain ε = 800 $\mu\varepsilon$ at the gauge location. Four identical 120 Ω foil strain gauges (gauge factor $k \approx 2$) are arranged in a full bridge with 5.0 V excitation. All four gauges experience the same temperature rise of +30 °C.

2.2.1 Derive the bridge output U_A with two active gauges in tension and two in compression.

2.2.2 Show why a full bridge largely cancels temperature effects.

2.2.3 If the adhesive allows only $I_{\text{exc}} \leq 15$ mA to avoid self-heating, check compliance.

Task 2.3: Silicon piezoresistive membrane pressure sensor: bias-point design

A square silicon diaphragm carries four diffused piezoresistors in a full bridge. At rated pressure, the longitudinal surface strain is +500 $\mu\varepsilon$ at two opposite edges and −500 $\mu\varepsilon$ at the other two. Each resistor is nominally 3 kΩ, with piezoresistive gauge factor k_π = 80 (n-type).

2.3.1 Find the small-signal bridge sensitivity $S = dU_A/dp$

2.3.2 Discuss why silicon (vs. metal SG) achieves much higher sensitivity and how temperature-dependent ρ enters

Task 2.4: Hall vs field-plate (Gaussian/MR) for isolated current sensing

Measure up to 200A DC through a busbar with 1 mm air gap using either:
A. a Hall plate ($d = 10\ \mu$m, $b = 200\ \mu$m, $I_x = 5$ mA); or
B. a field-plate MR element ($R_0 = 1$ kΩ, $\alpha \approx -0.004$ K^{-1}).
Flux density at full scale: $B = 80$ mT.

2.4.1 For A, estimate U_H using $U_H = (A_H B/d)I_x$ with a typical semiconductor A_H.

2.4.2 For B, use 5 mA constant-current bias and the $R(B)$ characteristic to estimate ΔV.

2.4.3 Compare temperature robustness and reasons to pick A vs. B.

Task 2.5: Magnetostrictive position sensor: time-of-flight and linearity
A magnetostrictive rod (wave speed $v = 2850$ m/s) is used in a non-contact absolute position transducer. A torsional pulse is launched at $t = 0$ and detected after interacting with a magnet placed at unknown position x along a 0.6 m rod. The measured time is $t = 152\ \mu$s.

2.5.1 Estimate x.

2.5.2 Correct for the electronics delay of 3.0 μs.

2.5.3 Temperature effect on position error.

2.5.4 Principle of operation (Villari and Wiedemann effects).

Task 2.6: Eddy-current proximity sensor: oscillator detuning and metal target
An inductive proximity sensor uses an LC oscillator with $L = 120\ \mu$H, $C = 680$ pF. A conductive aluminium target causes an inductance drop $\Delta L = -12\%$ at the switch point due to eddy currents.

2.6.1 Find the free-run frequency and the switch-point frequency.

2.6.2 Explain why conductive non-magnetic targets reduce L and how coil Q plays in detection margin.

Task 2.7: Capacitive thickness gauge with fringing
A non-contact thickness sensor measures a plastic sheet ($\varepsilon_r = 3.0$) with parallel electrodes $A = 4$ cm^2 and nominal gap $d = 0.50$ mm. Sheet thickness variations Δd are to be resolved.

2.7.1 Compute nominal capacitance C_0.

2.7.2 If the sheet bows, causing a +5% fringing-equivalent increase in effective area, estimate the apparent thickness error if the parallel-plate model is used.

Task 2.8: Field-plate (Gaussian effect) tacho vs toothed wheel: waveform and calibration
A field-plate bridge measures speed via a steel toothed wheel. Bridge excitation $U_{\text{exc}} = 3.3$ V, nominal arm $R_0 = 1.2$ kΩ. At the peak of a tooth the active element resistance increases by +8%.

2.8.1 Output waveform and shape

2.8.2 Estimate peak-to-peak output

2.8.3 If the element self-heats by +15 K, estimate the DC drift using $\alpha \approx -0.004\ \mathrm{K}^{-1}$ and discuss compensation.

Task 2.9: Thermistor/RTD Self-Heating: Measurement-Current Limit

An RTD with $R(25°\mathrm{C}) = 100\ \Omega$ measures air temperature. The thermal resistance to ambient is $\Theta = 400$ K/W. The readout uses a constant current I. Allow at most +0.2 °C self-heating error.

2.9.1 Find the maximum measurement current $I_{\max}$.

2.9.2 If the response time is dominated by thermal capacitance $C_{\mathrm{th}} = 30$ mJ/K, estimate the time constant τ and discuss the speed/accuracy trade-off.

Task 2.10: Hall Current Sensor with Magnetic Circuit: Sizing and SNR

A C-core with a 1.0 mm gap surrounds a conductor carrying up to 150 A DC. The mean magnetic path length is $l_m = 120$ mm, $\mu_r = 2000$. A Hall plate with thickness $d = 20\ \mu$m and bias current $I_x = 8$ mA sits in the gap.

2.10.1 Estimate the magnetic flux density B in the gap at full scale.

2.10.2 Estimate the Hall voltage U_H for a semiconductor and a metal.

2.10.3 Give two reasons why a Hall sensor is preferred over an inductive pickup in this application.

Task 2.11: Light Barrier Sensor for Fast Conveyor

A sensor is needed for a "light barrier" application . The sensor must detect when a box on a fast-moving conveyor belt ($v = 2$ m/s) breaks a 1 cm wide light beam. The beam break time is:

$$t = \frac{0.01\ \mathrm{m}}{2\ \mathrm{m/s}} = 5\ \mathrm{ms}.$$

The sensor's output must react within this time. Two components are considered (both based on the internal photoelectric effect):

1. Photoconductor (Photoresistor)
2. Silicon Photodiode

The text states that photoconductors are slow (response in seconds at low light) while photodiodes are fast (usable up to GHz).

2.11.1 Explain the physical reason for this major difference in response speed.

2.11.2 Which device is the only viable choice for this 5 ms application?

Task 2.12: NTC Thermistor and Linearization

An NTC thermistor (Negative Temperature Coefficient resistor) is used to measure temperature. Its resistance follows:

$$R(T) = R_N \, e^{B\left(\frac{1}{T} - \frac{1}{T_N}\right)}$$

with the following parameters:

- Nominal resistance $R_N = 10$ kΩ at $T_N = 25$°C (298.15 K)
- Material constant $B = 3950$ K

2.12.1 Calculate the sensor resistance $R(T)$ at $T = 0$°C and $T = 50$°C.

2.12.2 Explain qualitatively how adding a parallel resistor R_P helps linearize the sensor output.

Exercise 03: Signal Conditioning

Task 3.1: Band-Stop Filter

The signal conditioning section of an instrumentation system requires a tunable filter at its input in order to reject selected spot frequencies in the range 1 kHz to 3 kHz. The circuit chosen to undertake this filtering task is the *Wien frequency bridge*, as shown in Figure 3.1.1, having component values as follows:

$$C_1 = C_2 = 0.01\,\mu\text{F}, \qquad R_3 = 100\,\text{k}\Omega.$$

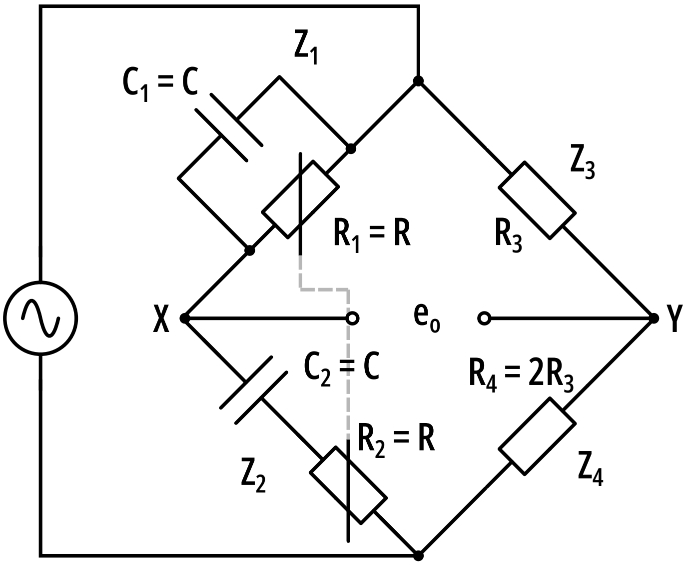


Figure 3.1.1: Wien frequency bridge circuit

3.1.1 State a suitable value for R_4.

3.1.2 Calculate the higher and lower values of R_1 and R_2 necessary to achieve the required frequency coverage.

Task 3.2: Shering Bridge

A transducer sensor having a passive impedance comprising a capacitance of 0.1 μF in series with a resistance of 500 Ω is interfaced to a signal conditioning system by a Schering bridge as shown in Figure 3.2.1. With no stimulus applied to the sensor the bridge is in balance and the output voltage, e_0, is zero. The bridge component values at balance are as follows:

$$C_1 = 0.025\ \mu\text{F}, \qquad C_3 = 0.1\ \mu\text{F}, \qquad R_1 = R_2 = 2\ \text{k}\Omega,$$

R_4 and C_4 together comprise the sensor, and the a.c. supply is 10 V at a frequency of 1 kHz. If the sensor is stimulated so causing its capacitance to increase by 10%, calculate the bridge output voltage.

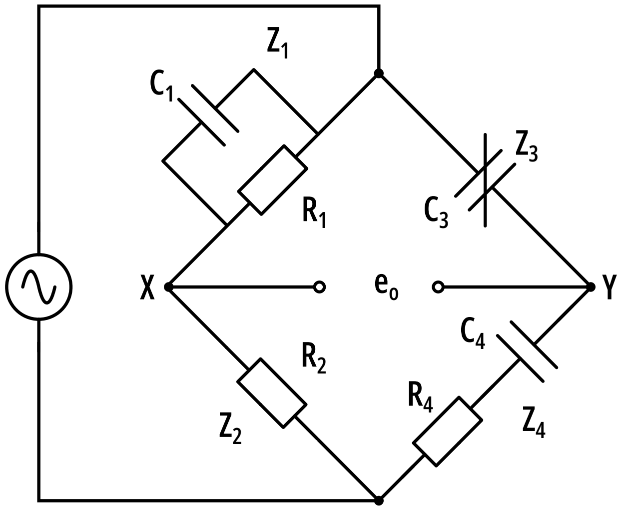


Figure 3.2.1: Figure 1.10 The Schering bridge.

Task 3.3: Operational Amplifiers output

For each of the circuits shown in Figure 3.3.1, calculate the output voltage e_0.

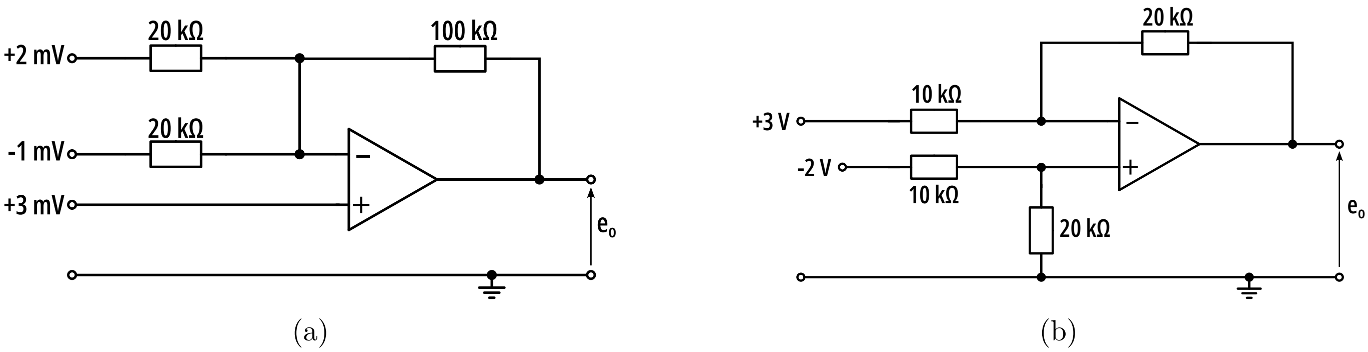


Figure 3.3.1: Circuits for task 3.3

3.3.1 (a) Summing Amplifier Circuit

3.3.2 (b) Differential Amplifier Circuit

Task 3.4: Inverting Op-Amp

An inverting operational amplifier circuit has an overall voltage signal gain of 19.5 dB. If the input resistor is 10 kΩ and the feedback resistor 100 kΩ. Assume a negligible signal source impedance.

3.4.1 Calcualte the feedback fraction, β

3.4.2 Calculate the amplifier open loop gain in decibels.

Task 3.5: Inverting Op-Amp with T-Resistance Network

For Figure 3.5.1 show that the gain of the circuit is approximately given by:

$$A_v \approx -\frac{R_f}{R_1}\left[1 + \frac{R_2}{R_3}\right]$$

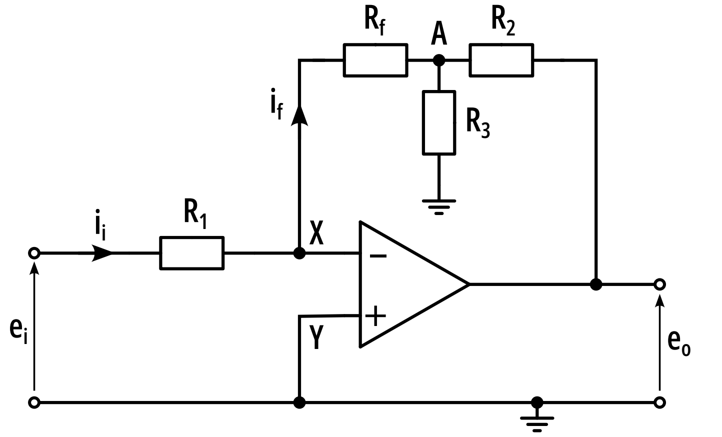


Figure 3.5.1: T-resistance network as feedback

Task 3.6: Programmable Gain Op-Amp

If in Figure 3.6.1 a logic 1 transistor-transistor logic (TTL) input closes the relevant switch, calculate the output voltage for the case where $E_i = 2$ mV and:

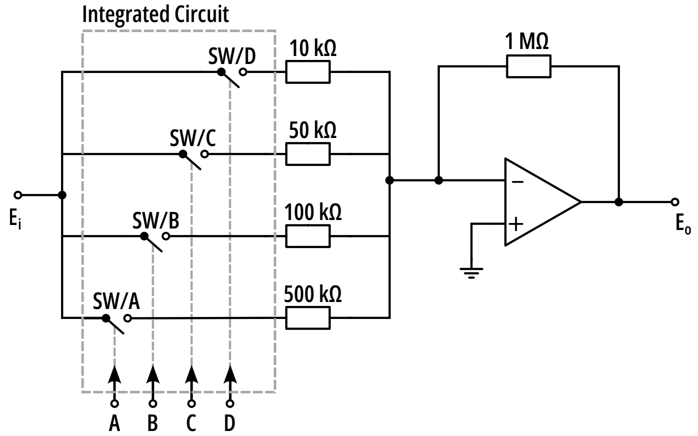


Figure 3.6.1: Programmable Gain Op-Amp

3.6.1 TTL digital input word is 1001.

3.6.2 TTL digital input word is 1001.

Task 3.7: Transducer and Op-Amp

A transducer bridge and an operational amplifier are connected as per Figure 3.7.1. $E = 10$ V, $R_f = 50$ kΩ and $R = 120$ Ω. The transducer has a passive resistance $R_x = 120$ Ω and is stimulated such that its resistance changes by 0.1%. Calculate the amplifier output voltage.

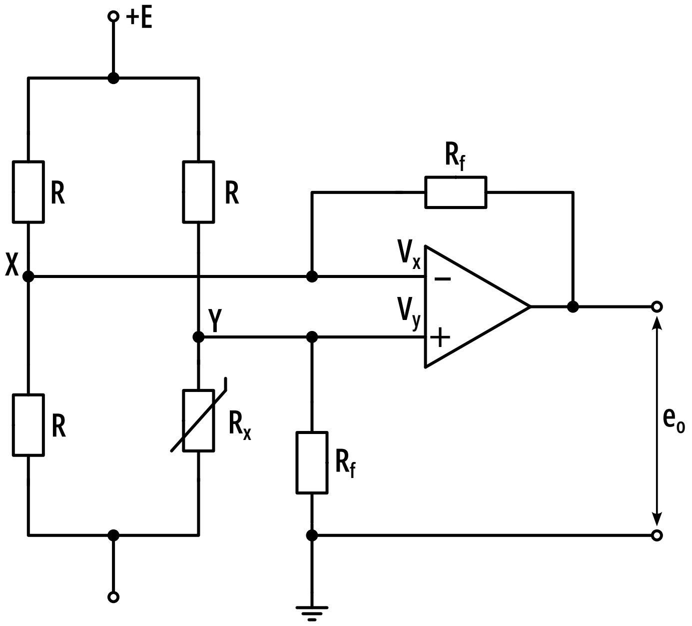


Figure 3.7.1: Transducer and Op-amp

Task 3.8: Capacitor Multiplier Circuit Analysis

A signal conditioning situation requires the use of a special capacitor having a value of 4780 μF. Unfortunately the most suitable capacitor available is only 1000 μF so it is decided to use the circuit shown in Figure 3.8.1 effectively to increase the value of the capacitor to 4780 μF.

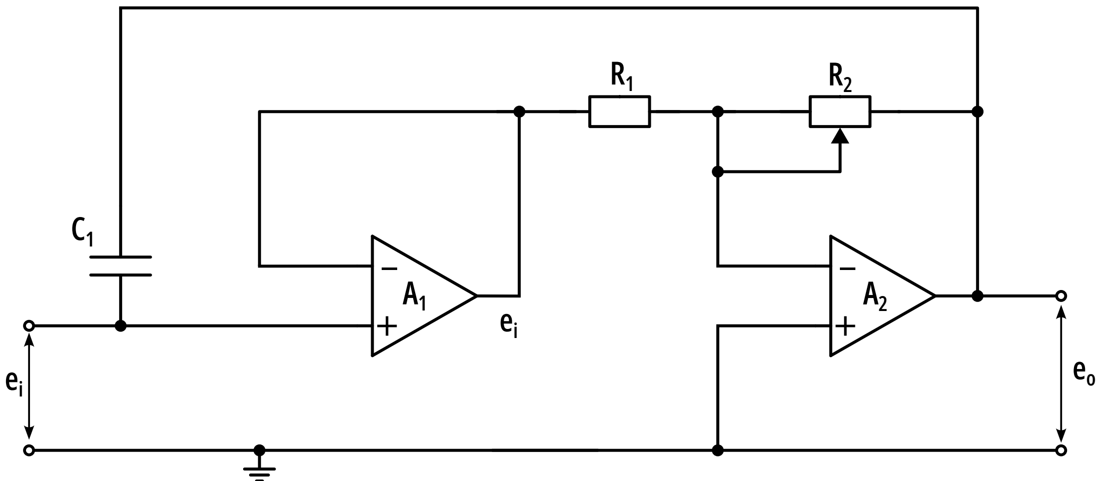


Figure 3.8.1: Capacitor Multiplier Circuit

3.8.1 Calculate the Required Gain (A_{V2})

3.8.2 Suggest Suitable Resistor Values (R_1 and R_2)

Task 3.9: Amplifier Noise and SNR Analysis

An antenna of noise temperature 160 K feeds a signal to an amplifier of noise temperature 260 K, bandwidth 2 MHz and power gain 90 dB. The SNR at the amplifier input is 30 dB. Assuming k to be 1.38×10^{-23} J/K, calculate the output signal power and the output SNR.

3.9.1 Convert Parameters to Linear Units

3.9.2 Calculate Reference Input Noise Power (N_A)

3.9.3 Calculate Output Signal Power (S_{out})

3.9.4 Calculate Output SNR (SNR_{out})

Task 3.10: Amplifier Noise and SNR Analysis

A 30 μW signal, having a SNR of 35 dB, is amplified by an amplifier of power gain 20 dB. The internal noise generated by the amplifier is equivalent to an additional noise power of 6 nW at its input. Calculate:

3.10.1 Parameters in Linear Units

3.10.2 Input noise power caused by the 35 dB input SNR

3.10.3 Output Signal Power (S_{out})

3.10.4 Total output noise power

3.10.5 Calculate the Output SNR (SNR_{out})

Exercise 04: Analog and Digital Conversions

Task 4.1: Digital-to-Analog Converter (DAC) Output Calculation

A 7-bit DAC has the digital input word 1100111_2 and a reference voltage of 8 V.

Calculate:

4.1.1 Analog Output Voltage

4.1.2 Conversion Resolution Voltage

Task 4.2: Analog-to-Digital Converter (ADC) Quantization

An 8-bit ADC has a reference voltage of 10 V and an analogue input voltage of 6.875 V.

Calculate:

4.2.1 Digital Output Word

4.2.2 Percentage Resolution

Task 4.3: DAC Reference Voltage Calculation

A 6-bit DAC is required to produce an output voltage of 9 V when all six input bits are at logic 1.

Calculate the required reference voltage for this DAC.

4.3.1 Reference Voltage

Task 4.4: 4-bit Weighted DAC Error Analysis

A 4-bit weighted inverting DAC has the following parameters:

- Reference voltage: $V_R = 1$ V
- Feedback resistor: $R_f = 8R$
- Input resistors (MSB → LSB): R, $2R$, $4R$, $8R$

We calculate the output voltage V_{out} step by step using the current summation method.

4.4.1 Find currents through each resistor

4.4.2 Total current and output voltage

4.4.3 Compute V_{out} for all 16 inputs

4.4.4 Compare with given DAC outputs

4.4.5 Assuming the electronic switch is working correctly, state the most likely cause of the DAC functioning incorrectly.

Task 4.5: R-2R Ladder DAC Output Calculation

A 4-bit R-2R ladder DAC has the following parameters:

- Reference voltage: $V_{\text{ref}} = 10$ V
- Ladder resistor: $R = 20$ kΩ
- Feedback resistor: $R_f = 50$ kΩ
- Op-amp supply limits: ±18 V

4.5.1 Output Voltage for Input 1001

4.5.2 Maximum Digital Input Word That Can Be Converted

Task 4.6: AD Conversion with successive approximation

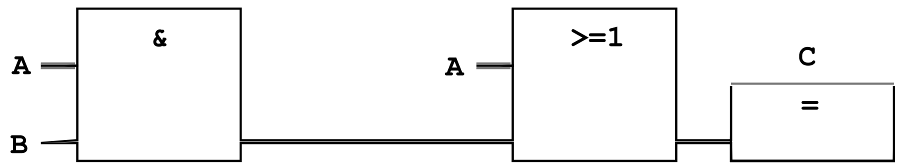
A 12-bit converter with an input voltage range of 0-10V converts a voltage of 7.1875V.

4.6.1 Calculate the number of conversion steps (Clock cycles) necessary to get the exact result as a digital number.

Exercise 05: PLC

Task 5.1: Logic Analysis (1)

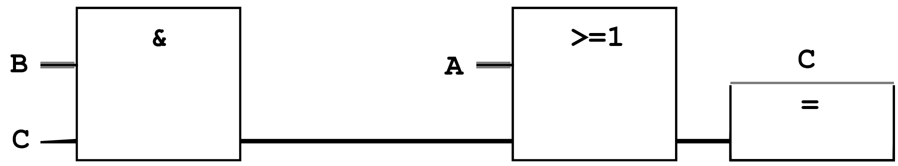
The logic below is given: Please analyse it and simplfy it !



5.1.1 Analog Output Voltage

Task 5.2: Logic Analysis (2)

Which function is fulfilled by the logic below ?



Task 5.3: PLC Statement List (STL) Representation

5.3.1 What does the representation of
- the conjunction (AND function) of the inputs I0.0, NOT I0.1 and I0.2 and
- the assignment of the result of the logic operation RLO to the output Q0.0 in the form of a statement list (STL) of a PLC look like?

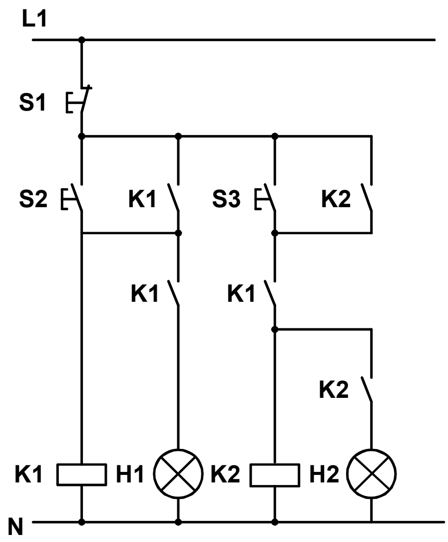
5.3.2 What does the representation of
- the disjunction (OR function) of the inputs I1.0, I1.1, NOT I1.2 and
- the assignment of the RLO to the output Q0.1 and to the Memory bit M 9.1 in the form of a statement list (STL) of a PLC look like?

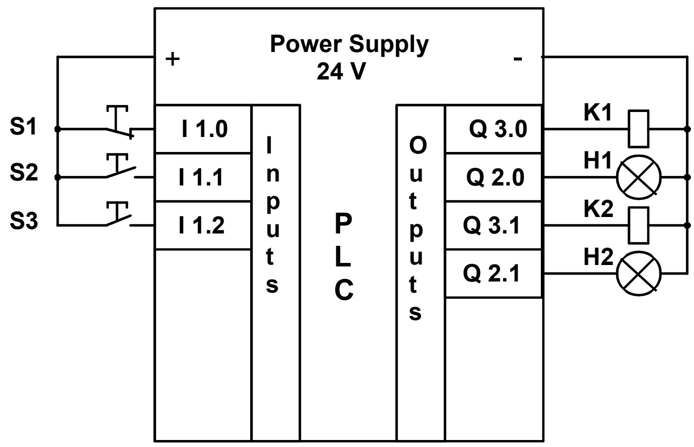
Task 5.4: Contactor circuit

The contactor circuit is given below:
Please find the PLC internal circuit in the Function Block Diagram (FBD) which is equivalent to the contactor circuit !

Task 5.5: LAD Representation of a Two-Staged Boolean Operation

Please create the LAD representation of a two staged boolean operation which complies with the following description:
The result of the OR operation with the inputs I 25.7 and I 26.0 is to be linked into an AND operation with the inputs I 10.6 und I 10.7. The result is to be assigned to the output Q 8.0.





Task 5.6: Emulation of the Antivalence (XOR) Operation in a PLC

How is the antivalence operation (XOR) to be emulated, if it is not contained in the basic operation pool of a certain PLC?

5.6.1 STL

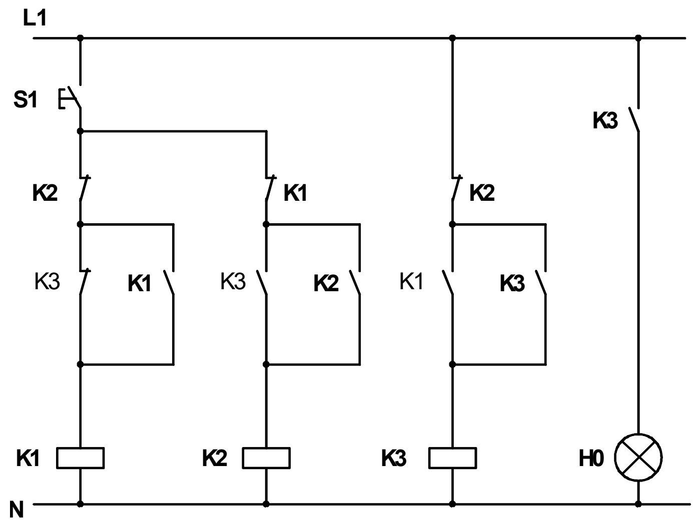
5.6.2 LAD

5.6.3 FBD

Task 5.7: Pulse Switch

Problem: Substitution of a contactor circuit by a PLC

List of Variables



Symbol	Absolute	Comment
S1	I 1.0	Momentary-contact switch
H0	Q 2.2	Lamp
K1	M 0.0	Memory bit
K2	M 0.1	Memory bit
K3	M 0.2	Memory bit

Functional description: If the pushbutton S1 is pressed, the contactor K1 is switched on as long as the pushbutton is pressed. At the same time the contactor K3 is switched on and holds itself and the lamp H0 is on.

If the pushbutton S1 is pressed again, contactor K2 is switched on. Thereby contactor K3 drops and the lamp is off.

The procedure can be repeated arbitrarily.

The pushbutton is wired to the input I 1.0. Contactors are to be emulated by memory bits. The output Q 2.2 is directly connected to the lamp.

Please create:

5.7.1 The hardware configuration

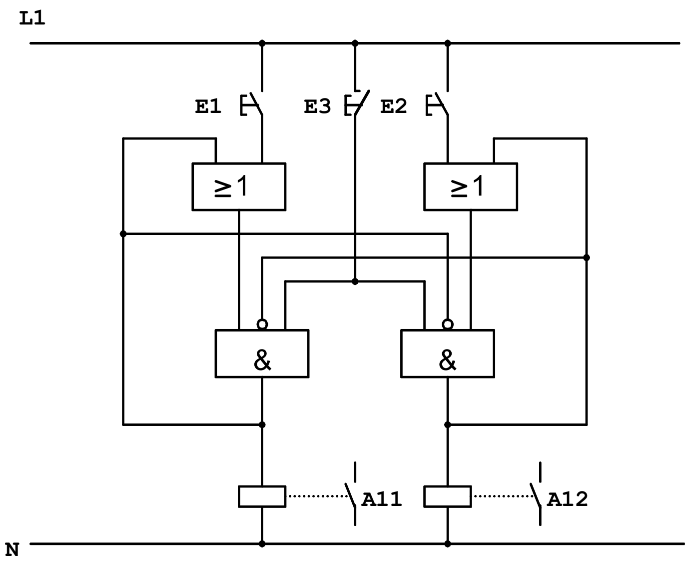
5.7.2 The LAD

Task 5.8: Motor Control Circuit

A function diagram of a motor control circuit is given:

5.8.1 Please specify the hardware configuration when using a PLC!

5.8.2 Please develop the statement list (STL)!



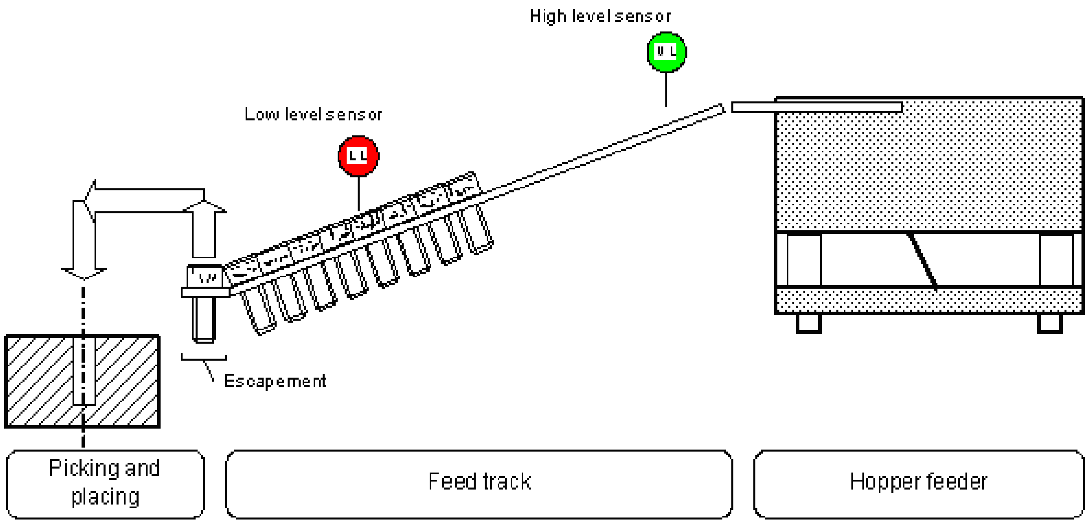
Task 5.9: Momentary Pulse in STL

Please give a sequence of statements for a so called momentary pulse in STL.

(A momentary pulse is the logic “1”-state of a boolean variable for exactly one program cycle as a reaction to the rising edge of another boolean variable.)

Task 5.10: Feed Track Control in a Parts Delivery System

The feed track in the parts delivery system should always contain enough parts to make sure that the picking and placing process can operate continuously without waiting for parts.
When the upper level switch sees a part for longer than 1 second, the motor of the hopper feeder should be switched off. It should be switched on if the lower level sensor sees no part for longer than one second.
A lamp indicates a failure state. This failure state is set in case of a congestion. It is reset by a pushbutton. The motor may not be on in case of a failure.



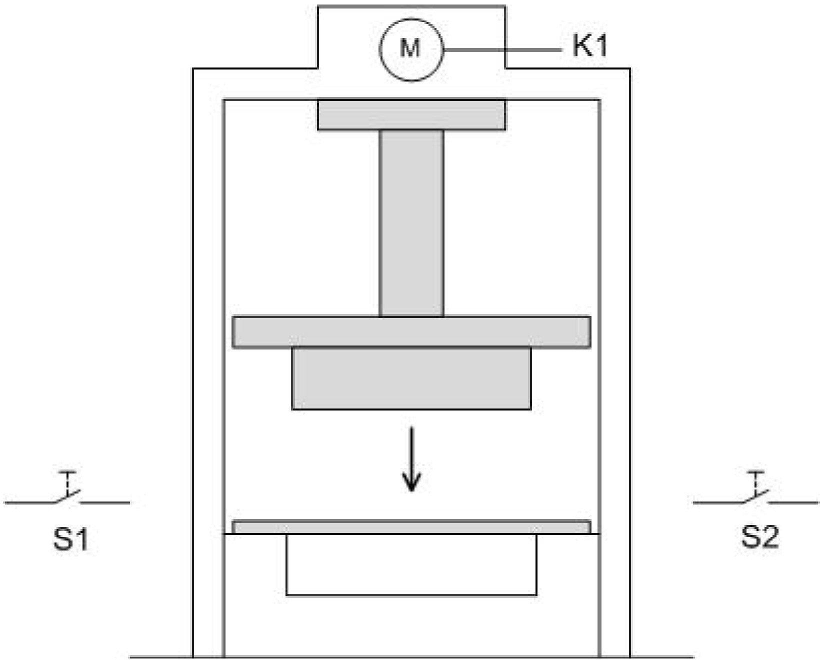
Wanted: Logic in FBD

Task 5.11: Manually operated press

This method is usually applied to protect the hands of the operators who operate dangerous machines. The machine only starts if both activation push buttons are pressed nearly at the same time (within 0.2 seconds). This has to happen using the left and the right hand.

The machine stops immediately if one of the pushbuttons is released.

Please develop a control program to operate the press cylinder while meeting the above safety requirements.



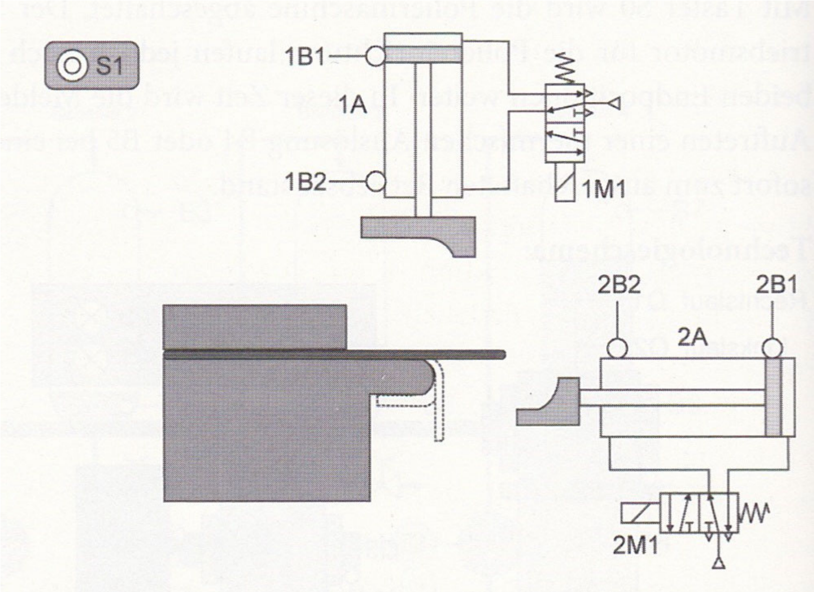
Task 5.12: Bending Tool

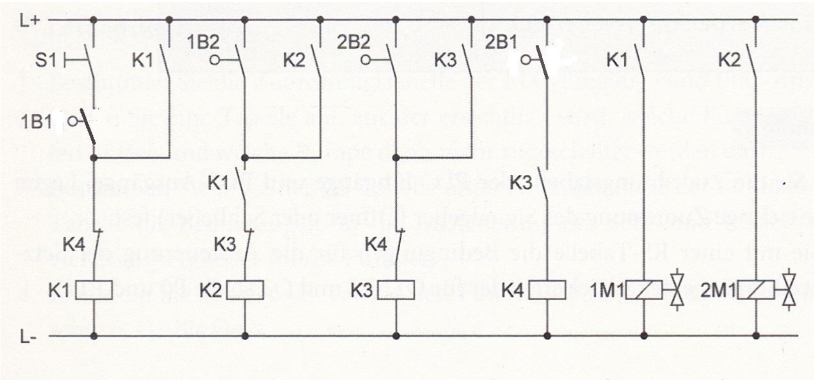
Metal sheets are bent to a certain shape using a bending tool. The bending sequence is as follows: After the pushbutton S1 was pressed, the piston of Cylinder 1A moves out. Thereby the sheet is clamped and pre-bent. When the piston of Cylinder 1A is in its outer end position, the piston of Cylinder 2A moves out, finishes the bending of the sheet and is retracted after it has reached its outer end position. When the inner end position of Cylinder 2A is reached, the piston of Cylinder 1A is also retracted.

The technology sketch below shows the arrangement of the cylinders.

The excitation of the solenoid valves was implemented up to now in a way as shown in the following circuit diagram:

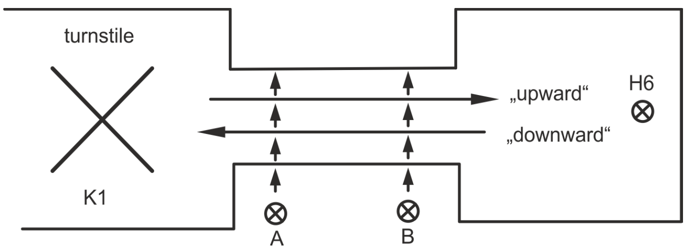
This contactor control shall be replaced by a software solution inside a PLC.





Task 5.13: Person counter

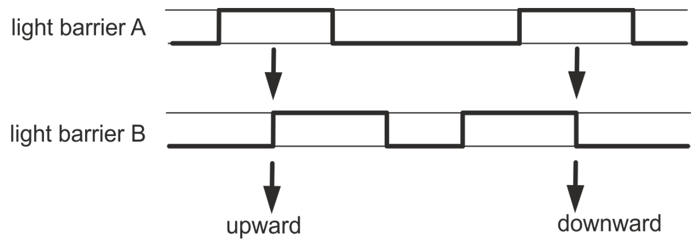
An Up-/Down-Counter is to be programmed. The persons in a room are to be counted. For this purpose, the entrance to the room is equipped with two light barriers which are installed in such a way that during the passage through the entrance first one and then both light barriers are interrupted. From that arrangement the counting signal is derived. The sketch shows the counting direction.



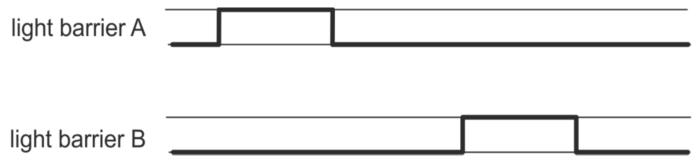
The light barriers provide a logic “1” signal if the beam is interrupted. The turnstile at the entrance is blocked if the room is occupied.

For resetting the counter, a pushbutton S3 is to be used. H6 is for room lighting. It is only on if there is someone in the room. K1 serves for the turnstile control. The maximum number of persons in the room is 10.

From the timing sequence of the interruption of the beams of light, the counting direction can be determined. If light barrier A is interrupted first, then the counting direction is upward. In case of counting direction "downward", light barrier B is interrupted first.



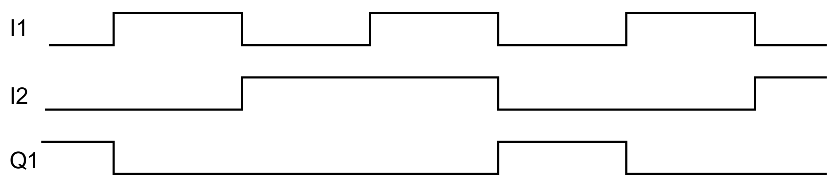
Precondition for counting is that at least one light barrier (in this example light barrier A) is interrupted. If now the state of signal B changes from "0" to "1", the counter counts upward. If B changes from "1" to "0", the counter counts downward.
If only one light barrier is interrupted, counting is prohibited.



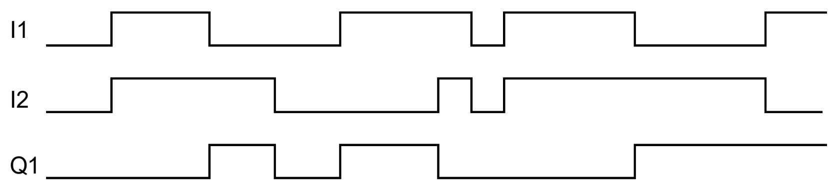
Here the precondition for counting is not fulfilled (signal state "1" for A and an edge at light barrier B).

Task 5.14: Generation of STL from a Timing Diagram
For the control function displayed in a timing diagram, the STL is to be generated.

5.14.1 a



5.14.2 b



Task 5.15: Analysis of a Statement List (STL)
The statement list below is given in STL:

```
A       I0.0
AN      M5.0
S       M5.0
AN      I0.0
R       M5.0
```

What happens here? Can this be done simpler?

Exercise 06: Digital Signal Processing

Task 6.1: Sampling

An analog signal composed of three sinusoidal components is given by

$$x(t) = 3\sin(7\Omega_0 t) + 5\sin(5\Omega_0 t) + 7\sin(11\Omega_0 t).$$

The signal is sampled to form a discrete-time signal.

6.1.1 What is the recommended sampling frequency for the given signal?

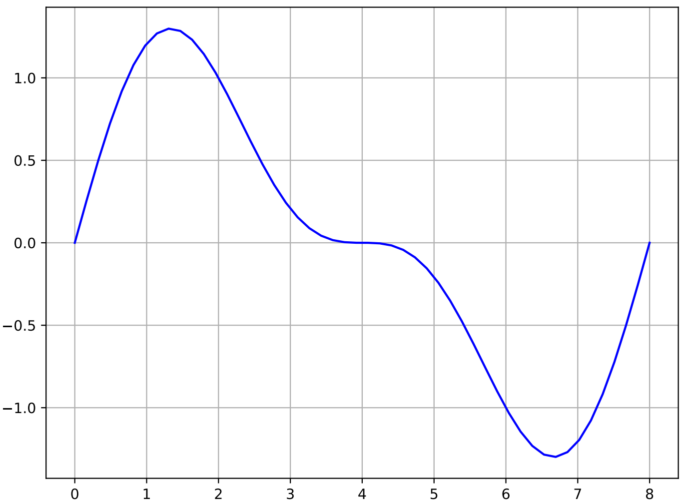
6.1.2 Derive an expression for the discrete-time signal obtained after sampling.

6.1.3 Explain the consequence of sampling the signal at a frequency of $10\Omega_0$.

Task 6.2: DFT and FFT Frequency Analysis

Consider the discrete-time signal

$$x[n] = \sin\left(\frac{2\pi}{8}n\right) + 0.5\sin\left(\frac{4\pi}{8}n\right), \quad n = 0, 1, \ldots, 7$$



6.2.1 Compute the Discrete Fourier Transform (DFT) $X[k]$ of $x[n]$ for $k = 0, 1, \ldots, 7$, and identify the frequency components present in the signal.

6.2.2 FFT Computation of the 8-Point Signal

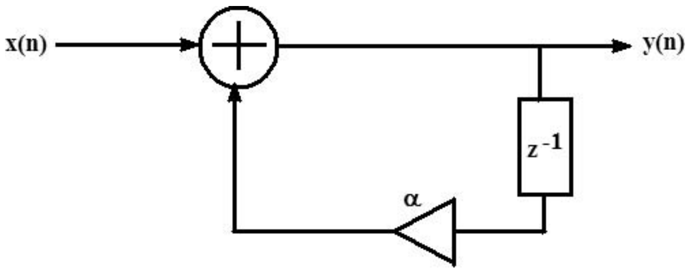
6.2.3 Draw FFT Flow Graph.

6.2.4 Explain how the Fast Fourier Transform (FFT) could be used to compute the same DFT more efficiently and compare the number of operations.

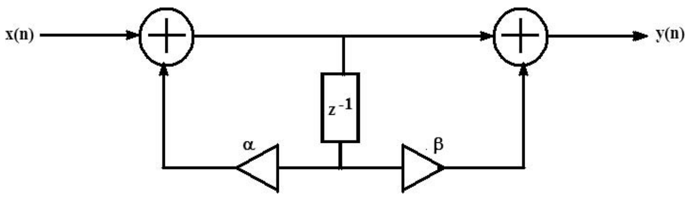
Task 6.3: Discrete Time Systems

Develop an expression between the input and output of the following discrete-time systems. Also mention the type of system and its order.

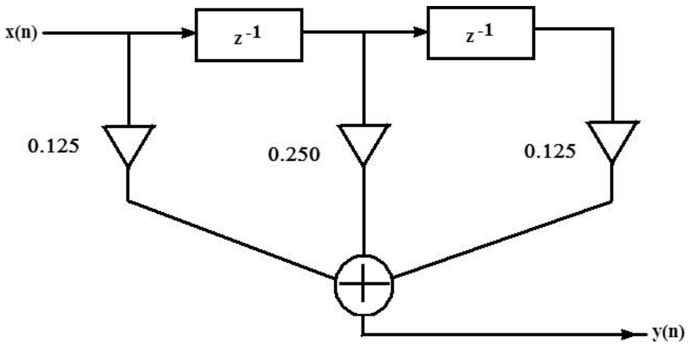
6.3.1



6.3.2



6.3.3



Task 6.4: Discrete-Time Fourier Transform (DTFT)

Compute the DTFTs of the following discrete-time signals using the Fourier transform analysis equation

$$X(e^{j\omega}) = \sum_{n=-\infty}^{\infty} x[n]e^{-j\omega n}.$$

6.4.1 $x[n] = \left(\frac{1}{2}\right)^{n-1} u[n-1]$

6.4.2 $x[n] = \left(\frac{1}{2}\right)^{|n|}$

Task 6.5: FIR Filter Design Analysis

A digital communication system requires a low-pass FIR filter to isolate a baseband signal. The design specifications are:

- **Passband Edge Frequency:** $f_p = 4$ kHz
- **Stopband Begin Frequency:** $f_c = 6$ kHz
- **Sampling Frequency:** $f_s = 20$ kHz
- **Maximum Passband Ripple:** $\delta_1 = 0.01$
- **Minimum Stopband Attenuation:** $\delta_2 = 0.001$

6.5.1 Transition Band Width

6.5.2 Ripple Ratio Calculation

Exercise 07: Industrial Communication

Task 7.1: RS 232 Serial Link

Two digital automation devices communicate via an asynchronous serial link according to RS 232 (CCITT V.24) with a transmission speed of 19.2 kBaud. The interface chips in both devices (UART = Universal Asynchronous Receiver/Transmitter) produce an interrupt to the CPU after receipt of a character (not of a bit!), so that the CPU can read the character from the receive buffer. Afterwards the chip receives the next character.

Data of the transmission link:

$$v_{\mathrm{kom}} = 19,2\ \mathrm{kBaud}; \quad \text{UART character format: 8 Data bits, Parity even, 1 Stop bit}$$

7.1.1 In which time interval is the CPU interrupted by the serial interface?

7.1.2 Please draw the logical state of the transmission channel as a function of time for the transmission of the characters "5" and "A" in ASCII representation (Hex 35 and 41).

7.1.3 How does the voltage on the transmit line look like as a function of time in this data transmission?

Task 7.2: RS485 Transmission

On a RS-485 transmission network the text string “Automation exercise run” is transmitted with a transmission speed of 500 kBaud asynchronously using UART characters.
Definition of the characters: 8 Data bits, parity even, 1 stop bit (PROFIBUS conform). Telegram propagation delay as well as software processing time are not to be considered.

7.2.1 No protocol overhead is to be assumed, i.e., exclusively user data are transmitted. How long does the transmission of a string last? How often can this text string be transmitted continuously in one second?

7.2.2 Now the PROFIBUS telegram SD2 is used. Before the send telegram the SYN time has to be awaited. As response a short acknowledge is to be taken into account. Per text string one such communication cycle is used. How many telegrams can be transmitted in one second?

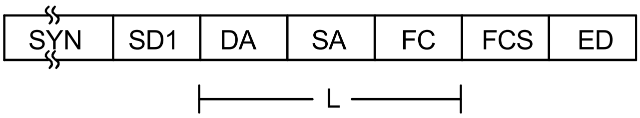
7.2.3 Now assume that a PROFIBUS master requests the telegram by polling with a SD1 telegram from a slave. The slave responds with a SD2 telegram. How many response telegrams can be transmitted in one second?

Telegram formats

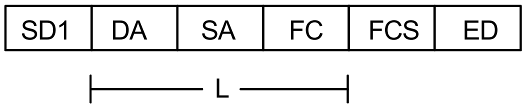
The figures contained in the following text don´t show sequences (Request ---> Acknowledge or response), but telegram formats of equal category (Hamming distance HD=4, fixed lenght with/without Data field and variable length), i.e. different acknowledge or response telegrams can follow the request telegrams (see Chapter 5).

Formats with fixed length of the information field without data field

A) Format of the request telegram (Request-Frame):



B) Format of the acknowledgement frame:



C) Format of the short acknowledgement

SYN = Synchronisation bits, min. 33 bit idle state
SD1 = Start byte 1 (Start Delimiter), Code: 10H
DA = Destination address
SA = Source address
FC = Frame Control
FCS = Frame Check Sequence
ED = End Delimiter, Code: 16H
L = Length of information field, fixed number of Bytes L = 3
SC = Single character, Code: E5H

Fig. Frame format with fixed legth without data field

7.2.4 How big is the protocol overhead in the cases 2 and 3?

Task 7.3: Calculation of Delay and Offset for Synchronization of Real Time Clocks

A slave clock is 50 μs later compared to a master clock. When the master has $T_{M1} = 1051$ μs on his clock, he sends a Sync telegram to the slave. When the slave is reading $T_{S1} = 1002$ μs on his clock, he receives the Sync telegram. The master reports the exact sending time with a Follow Up telegram, namely $T_{M1} = 1051$ μs. The slave now sets his clock ahead by the difference $T_{M1} - T_{S1} = 49$ μs.

7.3.1 Are the clocks synchronized now or is there still an error existing?

Shortly later the master sends a new Sync telegram at $T_{M2} = 1063\ \mu s$.

7.3.2 At which time on the slave clock T_{S2} is the slave receiving the telegram?

Now the slave is sending a Delay Request to the master. Sending time is $T_{S3} = 1080\ \mu s$. Symmetry is assumed.

7.3.3 At which time T_{M3} does the master receive the request?

7.3.4 What can be calculated by the slave after receiving the Delay Response?

7.3.5 Why is no Follow Up telegram needed after the Delay Request?