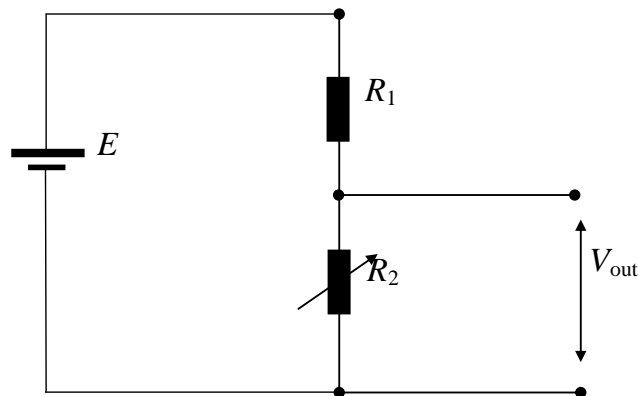


**Task 1:** A voltage divider is shown in the Figure below, where  $R_1$  is a semiconductor resistance that depends on the light and may have two different values: “dark” ( $R_1^{dark}$ ) and “light” ( $R_1^{light}$ ). The output voltage  $V_{out}$  is measured across a variable resistance  $R_2$  (usual resistance). At a fixed value of  $R_2$ , we obtain  $V_{out}^{dark}$  for  $R_1^{dark}$ , and  $V_{out}^{light}$  for  $R_1^{light}$ . Find the formula for the optimal value of  $R_2$  that provides the biggest difference  $V_{out}^{light} - V_{out}^{dark}$ .

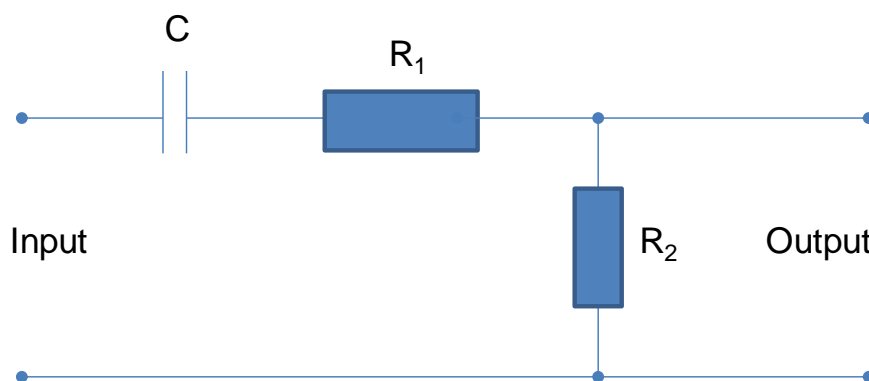


**Your answer:**

$$R_2^{optimal} =$$

(it must be expressed through  $R_1^{dark}$  and  $R_1^{light}$ )

**Task 2:** Find (formula) the time domain transfer function  $F(t > 0)$ , for the AC network shown in the Figure below. Use Eqs. (4.53)–(4.55) in Lecture 4.

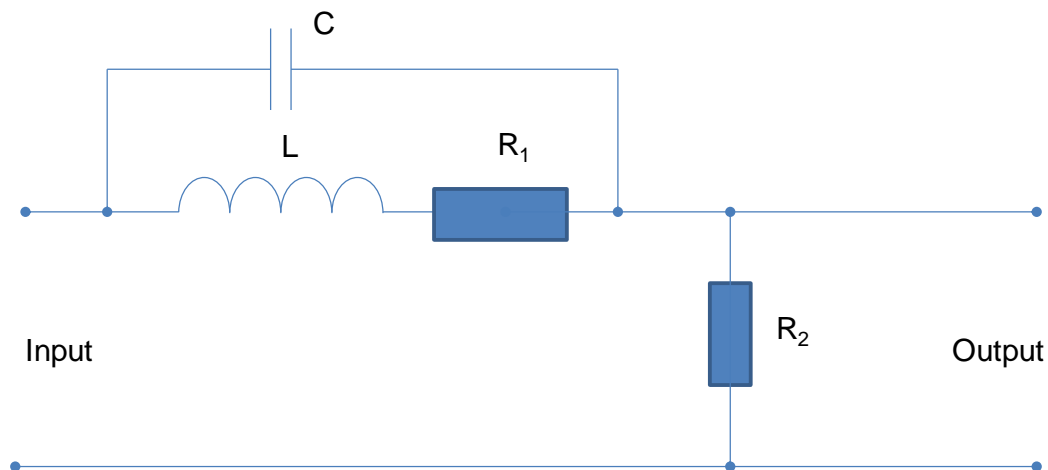


$$\hat{F}(\omega) = \frac{R_2 C \omega}{(R_1 + R_2) C \omega - i}$$
 is the frequency domain transfer function.

**Your answer:**

$$F(t > 0) =$$

**Task 3:** Find (formula) the time domain transfer function  $F(t > 0)$ , for the AC network shown in the Figure below. Use Eqs. (4.53)–(4.55) in Lecture 4.



$\hat{F}(\omega) = \frac{R_1 R_2 C \omega + i(\omega^2 LC - 1) R_2}{(R_1 R_2 C \omega + \omega L) + i(\omega^2 L C R_2 - R_2 - R_1)}$  is the frequency domain transfer function.

**Your answer:**

$F(t > 0) =$

**Task 4:** For the magneto-impedance (MI) sensor shown in the Figure below:

- Redraw the circuit in the form of a block diagram and signal flow graph, where each block is a linear network:

Excitation signal (sinusoidal or pulse) → [ ] → ..... → [ ] → Output DC level

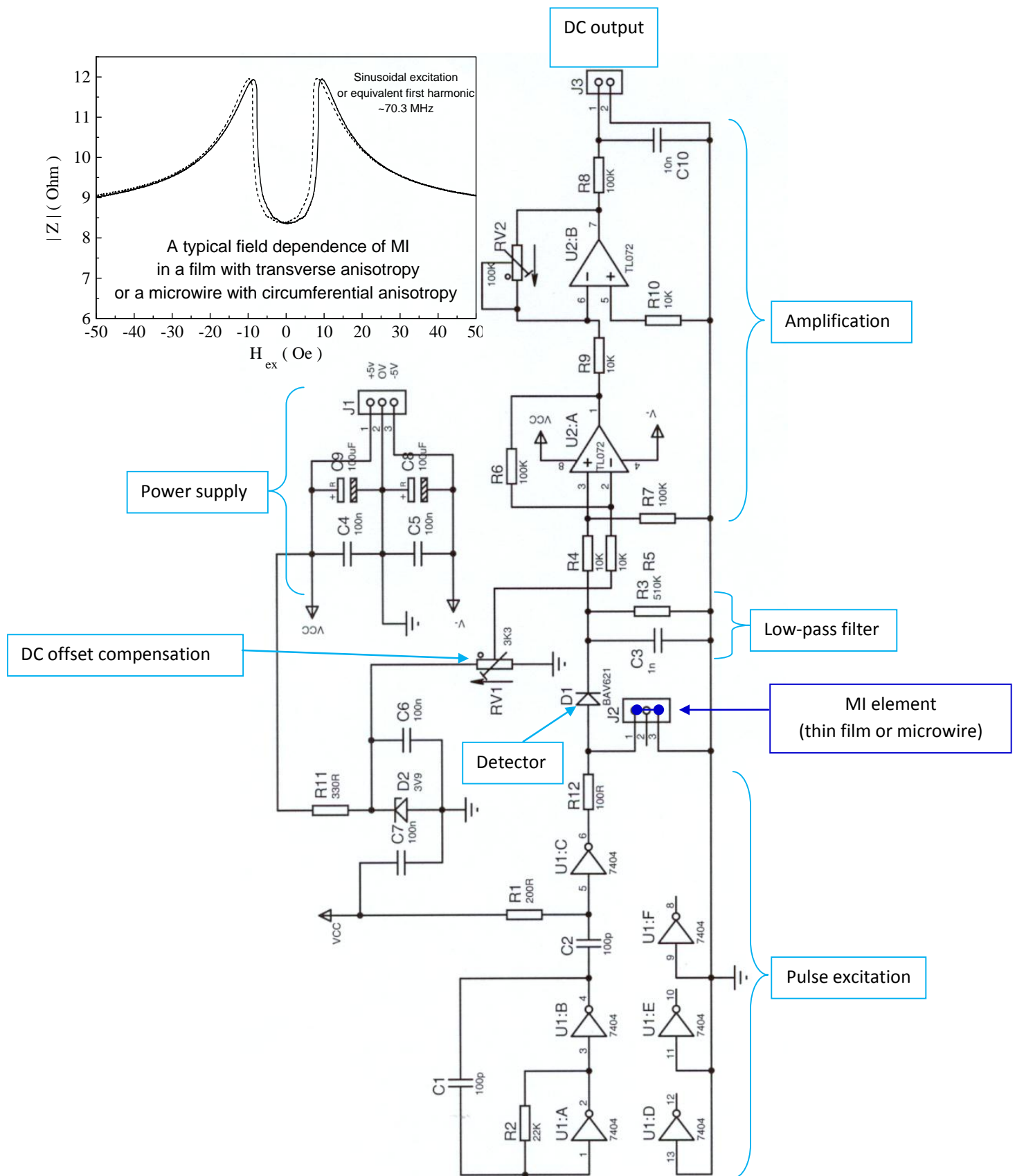
- Find the frequency domain or DC transfer function of each structural block [ ] in your block diagram:

[  $G(\omega)$  ]  $G(\omega) = \dots\dots$

- Can the MI element (wire or thin film) be represented as a linear network for a fixed magnetic field? If YES, please explain how (circuit and transfer function). If NO, please explain why.

For the circuit shown below. The 74AC04 is a C-MOS TTL device used for its high-speed switching and low current capability. U1:A and U1:B are configured as a multivibrator with capacitor C1 and resistor R2 forming the timing network to give an approximate 250 KHz square wave pulse generator. The output of the multivibrator is fed to a differentiator circuit comprising R1 and C2 that causes the leading edge of the square wave to become a positive going 50 ns pulse. This pulse is applied to U1:C to improve its shape and applied directly to the MI element. The power consumption of the above circuit is minimal due to the drive

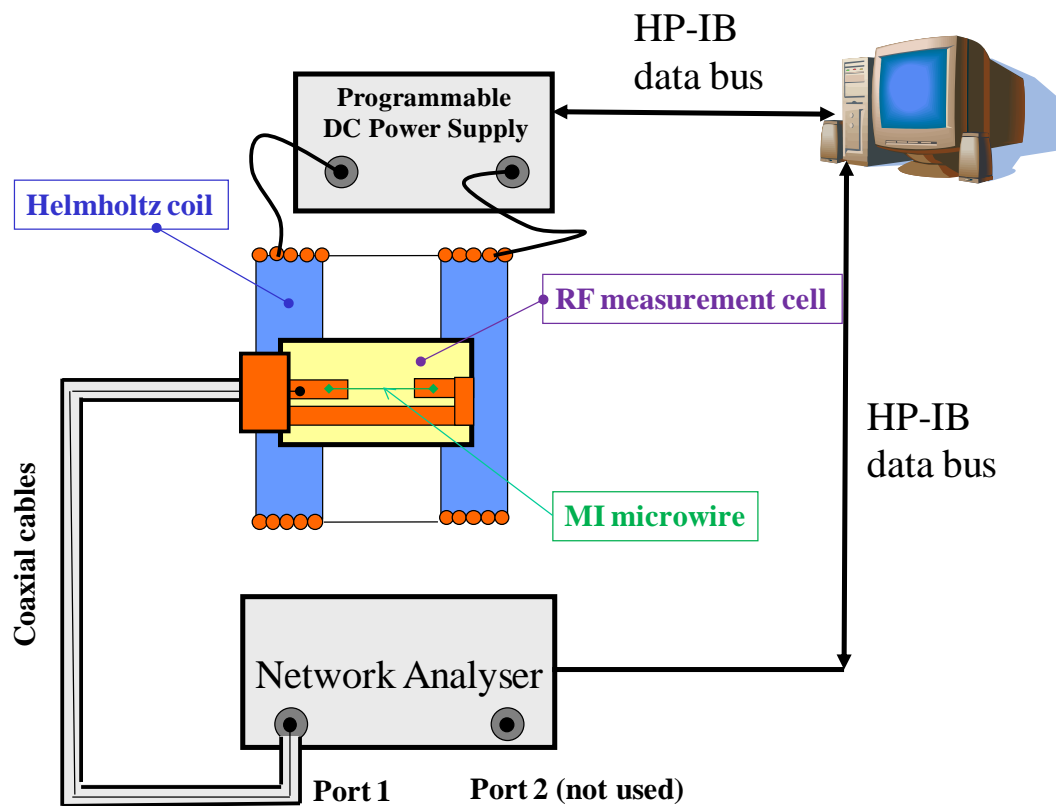
for the MI element being a pulse of 50 ns at a pulse repetition rate of 8.5 ns achieving a 1/165 of the maximum reduction in power. The MI element is connected between points “1” and “3” of the J2 connector, and its impedance is changed by an external magnetic field  $H_{ex}$  causing a change in the amplitude of the positive going pulse. A typical field dependence of MI is shown in the Figure above. The resistance R12 is chosen much bigger than the absolute value of MI impedance (at any  $H_{ex}$ ) to keep the excitation pulse-current amplitude constant. A Schottky high-speed detector D1 removes the negative half cycle caused by ringing of the MI and charges up C3 via R3 (100 Hz low pass filter) to give a DC voltage proportional to the applied magnetic field. Amplification of the DC is achieved by U3 (AD524) with a zero offset RV1, stabilized by D2, current set by R11 and decoupled by C6 to set the DC level to zero. U3 (AD524) is used to prove the system and would not be used in a working concern. The final DC output signal is taken from the J3 connector. It is envisaged that the basic components of the system would be a pulse generator, rectifier, and filter. Often the MI field dependence has low sensitivity in the vicinity of zero field. Then, to achieve a maximum field sensitivity the operating point should be shifted from zero value by an additional dc bias field along the sample. In this case, the electronic scheme will include an additional bias coil.



**Your block diagram and transfer functions for each block (use as many pages as you need)**

**Task 5:** Use the file “Impedance field dependence.xls” (attached). This impedance field dependence was measured for the 60.4 MHz sinusoidal excitation using our Agilent 8753E Vector Network Analyser, as shown in the Figure below (recall our practical work).

## MI network measurements: field measurements



**The attached file has 6 columns:** **A** – scanning magnetic field in Oersteds (from negative to positive), **B** – impedance real part in Ohms (for A field scan), **C** – impedance imaginary part in Ohms (for A field scan), **D** – scanning magnetic field in Oersteds (from positive to negative), **E** – impedance real part in Ohms (for D field scan), **F** – impedance imaginary part in Ohms (for D field scan). “**A**” is the direct field scan, i.e. from a large negative field to a large positive field. “**D**” is the return field scan, i.e. from a large positive field to a large negative field. For example, B(A) is the field dependence of the impedance real part for the direct field scan, and E(D) is the field dependence of the impedance real part for the return field scan.

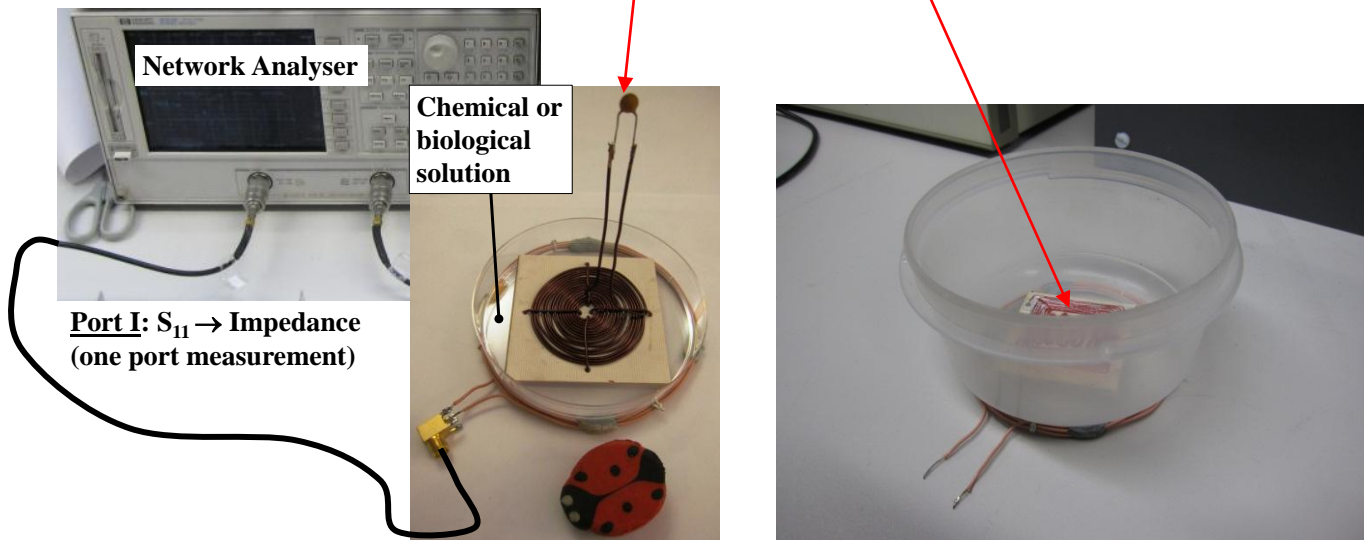
- Draw in one graph:  $\text{Re}[Z]=B(A)$ ,  $\text{Im}[Z]=C(A)$ ,  $\text{Re}[Z]=E(D)$ , and  $\text{Im}[Z]=F(D)$
- What is the hysteresis in these graphs?
- Draw  $|Z|$  – impedance module (see an example in Task 4) for the direct and return field scan (in one graph)
- Indicate the field operating point for  $|Z|$  used as a field-to-Ohm sensor characteristic
- How can the field operating point be provided?

**Your graphs and comments** (use as many pages as you need)

**Task 6:** Draw the circuit diagram of your magneto-resistive (MR) sensor, which you developed at the practical work, and explain the circuit operation principle.

**Your circuit diagram and comments** (use as many pages as you need)

**Task 7: Recall our LC resonance chemical sensor.** At the practical work, we have tested two different configurations: (1) with the planar capacitor, which is dipped into the bath together with the planar coil and (2) with the external capacitor, which is outside the bath.



- Explain the operation principle of these sensors.
- Explain why is the second configuration less sensitive to the permittivity change than the first one?
- Draw the equivalent circuit of these sensors (have a look at your lab sheet) and find (formula) the loop antenna impedance  $Z(\omega)$ , which takes into account the inductive coupling with the LC circuit.

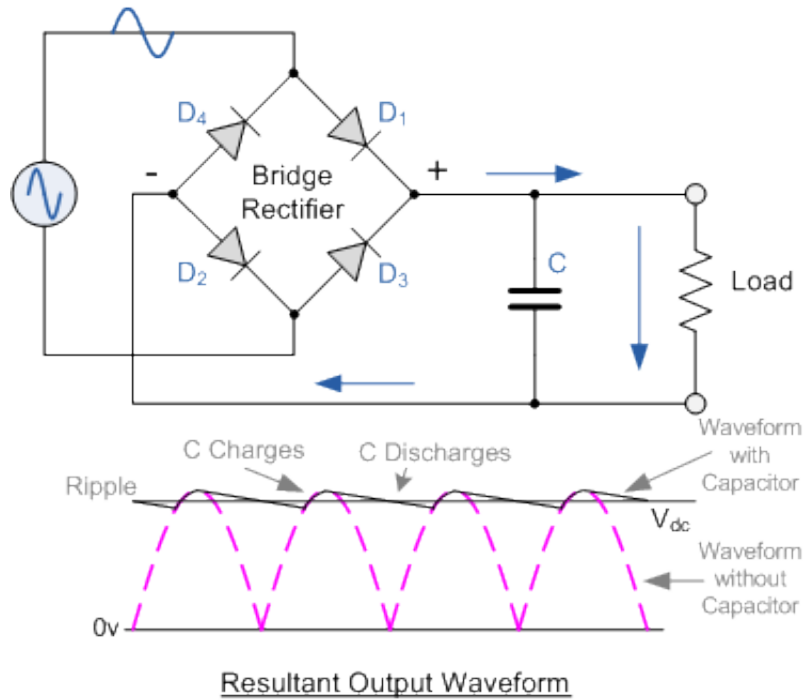
**Your circuit diagram and comments** (use as many pages as you need)

$Z(\omega) =$

**Task 8: Mathematical model of a stepping motor.**

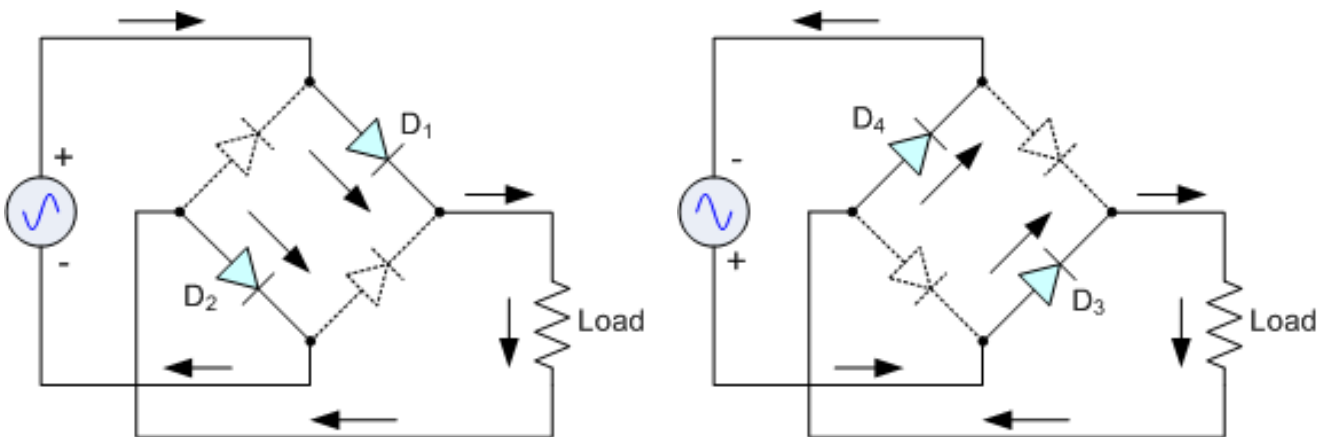
- Derive the differential equation which describes the operation principle of a stepping motor (in the linear approximation). This differential equation must be supplied with the initial conditions for each step – which ones?
- Find the general solution of this differential equation (formula) in the time domain for each step, where the previous step provides the initial conditions.
- Explain all the electro-mechanical limitations for this type of electric motors.

**Task 9: Mathematical model of the simplest full-wave rectifier.** The classical scheme of full-wave rectifier is shown in Fig. 1. Each diode is assumed to be an ideal switch which is characterised by zero pass resistance, infinite inverse resistance, and zero switching time.



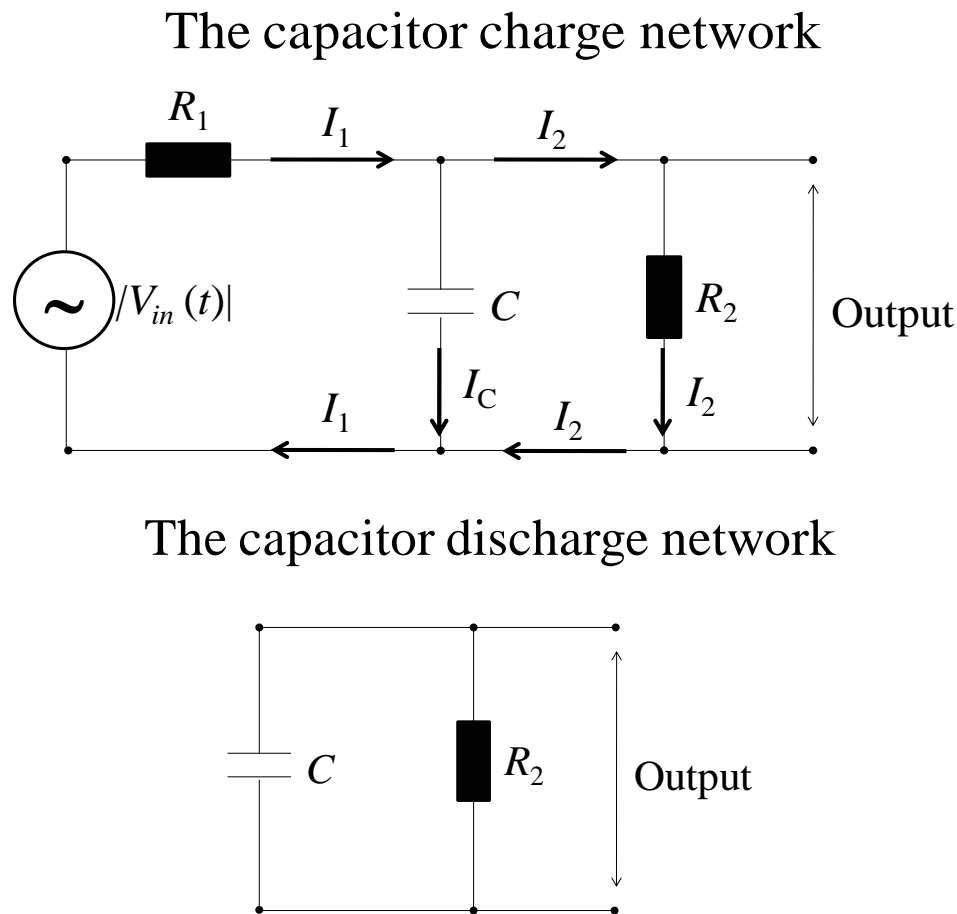
**Fig. 1 Full-wave rectifier.**

In the output circuit in Fig. 1, we have only one current direction (through the load) which is provided by the bridge connection of four diodes, as shown in Fig. 2. Therefore, after the rectifier we should have  $V(t) \sim |V_{in}(t)|$ , where  $V_{in}(t)$  is the AC input voltage.



**Fig. 2 Current directions in the full-wave rectifier.**

If a smoothing filter is attached to the rectifier output, its behaviour becomes more complicated. We will consider the simplest CR filter consisting of a capacitor connected in parallel to the load. The latter is assumed to be a resistor (not impedance). This circuit is described by the two linear networks, as shown in Fig. 3, where  $R_1$  is the resistance of the AC voltage source and  $R_2$  is the load resistance.



**Fig. 3 Two linear networks describing the rectifier operation.**

Due to the internal resistance  $R_1$ ,  $|V_{in}(t)|$  is not equal to the voltage across the input of the network attached to the rectifier output (RC filter in our case): we have a voltage divider. For each time moment  $t$ , if  $|V_{in}(t)|$  is larger than the voltage  $V_C(t)$  across the capacitor, we will have the capacitor charge process which is governed by the first  $R_1R_2C$  network. On the contrary, if  $V_C(t)$  is larger than  $|V_{in}(t)|$ , the diode bridge will be locked by the negative potential difference  $|V_{in}(t)| - V_C(t)$ , and hence the external AC voltage source will be electrically disconnected. In this case, at the filter output (across the load) we will have the capacitor discharge process which is governed by the second  $R_2C$  network. Finally, after several periods, we will obtain a steady output waveform  $V_C(t)$  that consists of the charge and discharge voltage curves.

- Derive the differential equations together with the initial conditions that describe the operation of this full-wave rectifier.
- Find the general solutions of these equations.

**Your equations and solutions (use as many pages as you need)**



### Task 10:

Modify the system of differential equations describing the operation of a DC motor (see Lecture 7)

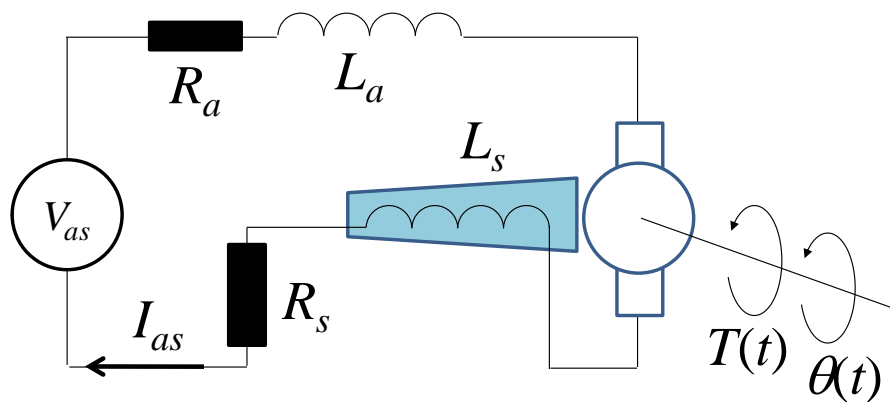
$$R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + K_b \frac{d\theta(t)}{dt} = V_a(t)$$

$$J \frac{d^2\theta(t)}{dt^2} + D \frac{d\theta(t)}{dt} + K\theta(t) = T(t)$$

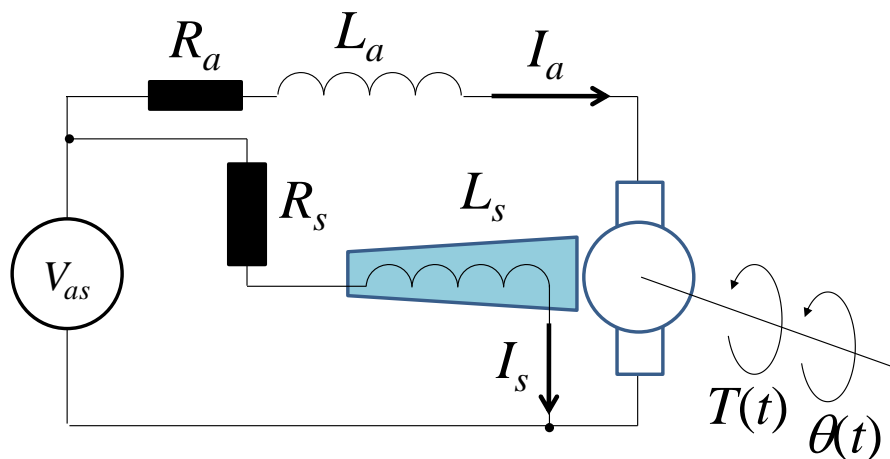
$$T(t) = K_t I_a(t)$$

for the following connection schemes:

a) The series connection of the stator and rotor

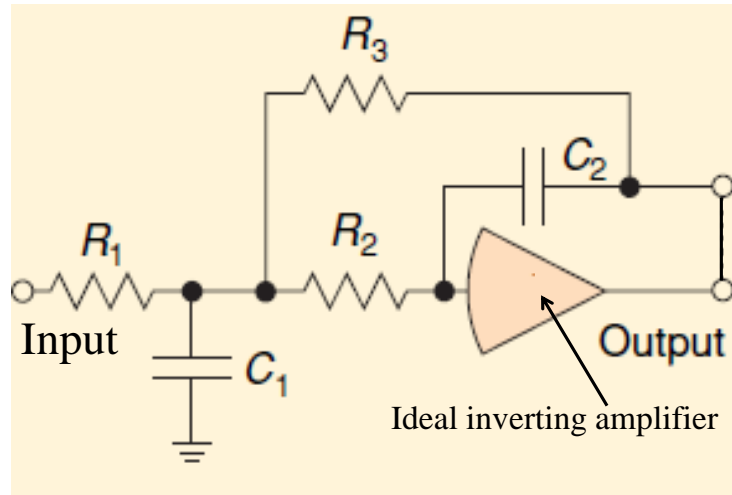


b) The parallel connection of stator and rotor



Your modified systems (a) and (b), but without solutions (use as many pages as you need)

**Task 11: Analog computer.** The circuit with an ideal inverting operational amplifier shown in the Figure below simulates a second-order linear system (electric or mechanical), where the circuit input is the system input parameter (force or torque, for example) and the circuit output is the system output parameter (displacement or rotation angle, respectively). **To prove this property, you have to find the transfer function of this electronic linear network in the frequency ( $\hat{F}(\omega)$ ) and time ( $F(t)$ ) domains.** Hint: Use the model approach explained in Lecture 6 (Kirchhoff's equations and loop analysis), but for an ideal OpAmp.



**Frequency and time domain transfer functions:**

$$\hat{F}(\omega) =$$

$$F(t > 0) =$$