Experiment 3: Eddy Current Proximity Sensor

Aims of the Experiment

You will apply the working principle of eddy current sensors, get experience working with LC resonators, study the influence of different materials on the LC-circuit and apply the LC-circuit as a proximity sensor.

Theoretical Background

An external magnetic AC-field of flux density B induces an electrical field E in a conductor with closed electrical field lines, which in turn causes an eddy current I_{ed} in the conductor (compare fig. 2.1). The eddy current is surrounded by a magnetic field B_i with a direction opposite to the change of the external magnetic field. Hence it works against the external magnetic field B which is equivalent to reducing the inductance L of the coil producing B. The opposite effect is obtained by ferromagnetic materials which increase the external magnetic field and increase the inductance of the coil. The eddy current effect and the ferromagnetic effect are competing phenomena. With increasing frequency, the ferromagnetic effect decreases, whereas the eddy current effect increases.

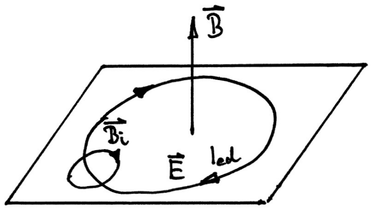


Fig. 2.1: Eddy current effect (drawn for an increasing external field B)

If the coil is part of an LC-resonator, the resonant frequency f_{res} changes with a change in the inductance L. The resonant frequency is given by

$$f_{res} = \frac{1}{2\pi\sqrt{LC}}$$

In an eddy current proximity sensor as depicted in fig. 2.2, the inductance L changes with the distance between the coil producing the external magnetic field and the conductor (metallic object). Hence the resonant frequency f_{res} is a function of the distance. In a free LC-oscillator, the resonant frequency can be measured directly. In a forced oscillator, a change in the resonant frequency changes the voltage drop U_C over the oscillator (compare fig. 2.3).

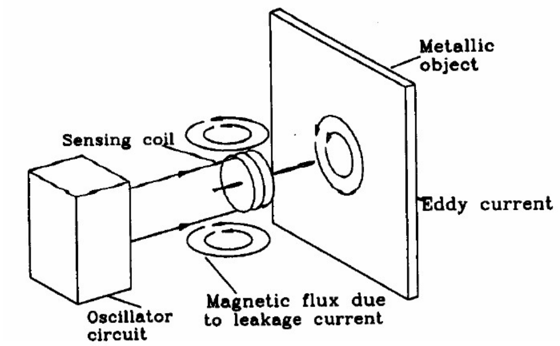


Fig. 2.2: Eddy current proximity sensor

Exercise 1: Frequency Response of an LC Band Pass Filter

Frequency Response of the LC band pass filter

Implement the band pass filter as shown in fig. 2.3. Connect the **wave generator** to the input of the circuit. Connect the **DSO** both to the input and the output of the circuit. The inductance L of the coil is fixed by the value of the coil provided. **Measure** the **inductance L** with an LC-meter. Choose the **capacitance C** to obtain a resonant frequency $\mathbf{f_{res}}$ of approximately **1.5 kHz**. Determine the exact value of the resonant frequency for the chosen capacitance, measure the amplitudes U_0 and U_C and calculate the ratio $A_{max} = U_C/U_0$ characterising the resonant frequency. What is the phase difference between the input voltage U_0 and the output voltage U_C at resonance?

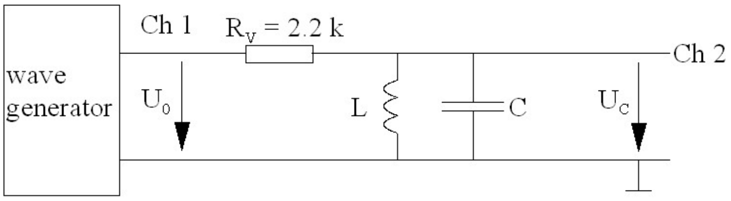


Fig. 2.3: LC band pass filter with forced oscillation

To obtain a rough **resonance curve**, determine the frequencies for A =0.7·A_{max} and for A = 0.2 ·A_{max} and measure the corresponding **phase angles**.

In the report, draw the resonance curve and the phase curve.

Exercise 2: Influence of Plates in the Proximity of the Coil

Set the input frequency of the wave generator to the measured **resonance frequency** found in Exercise 1. Put the **different plates** provided (**copper, iron, PVC**) directly at the front surface of the coil (the plate should touch the front surface of the coil) and measure the **voltage $\mathbf{U_C}$**. Now change the frequency of the wave generator to regain the resonance condition obtaining the **resonant frequency $\mathbf{f_{res}}$*** with a plate put in front of the coil. Measure the voltage U_C* (with plate). Calculate the relative change in the resonant frequency for each plate material

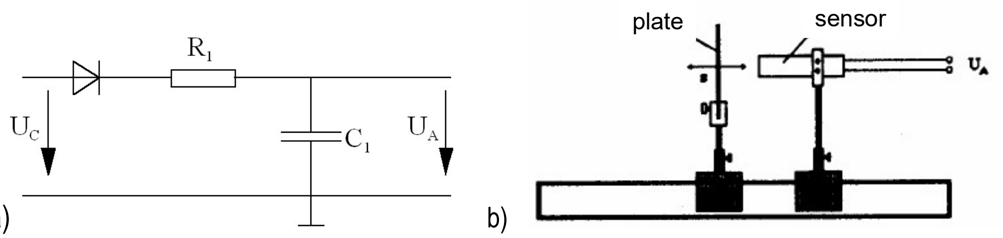
$$\Delta f_{res,rel} = \frac{f^*_{res} - f_{res}}{f_{res}}$$

Which material has the biggest influence based of $\Delta f_{res,rel}$?

Now choose a new **capacitance C** to obtain a **resonant frequency $\mathbf{f_{res}}$** without plate of approximately **10 kHz** and repeat the measurements with the plates as described above. Which material has the biggest influence? Explain your results in the lab report.

Exercise 3: Proximity Sensor

Set the frequency of the wave generator to the **resonant frequency $\mathbf{f_{res}}$** without plate of approximately 10 kHz. Rectify U_C with a diode and smooth the output voltage U_A with an RC low pass filter as shown in fig. 2.4 a. Record the **output voltage $\mathbf{U_A}$** in the table of the lab protocol as a function of the **distance s** of the copper plate from the coil. Choose reasonable distance increments [e. g. 1 mm]. Note that 1 turn of the distance knob causes a displacement of 2.5 mm. In the report, draw a diagram of U_A as a function of the distance s.



a) b)

Fig 2.4: a) Rectification circuit (e. g. R_1 = 1 kΩ, C_1 = 220 nF) b) set-up for distance measurement.

Acknowledgement

We thank Prof. Dr. B. Deppisch for providing the previous lab instruction material.

Experiment 2: Eddy Current Proximity Sensor

Names		**Lab Protocol**
		Date of Experiment

Exercise 1: Frequency Response of an LC Band Pass Filter

To be done before the lab
Assume the inductance L = 10 mH. Calculate the capacitance C to obtain the resonant frequency required.

measured inductance L of the coil provided	
calculated value for capacitance C ($f_{res} \approx 1.5$ kHz)	
chosen value for capacitance C	
measured value of the resonant frequency f_{res}	
supply voltage U_0 at f_{res}	10 V
voltage U_C at f_{res}	
maximum amplitude relation $A_{max}=U_C/U_0$ at f_{res}	

A		U_0 [V]	U_C [V]	frequency f	φ [°]
$0.2 \cdot A_{max}$					
$0.7 \cdot A_{max}$					
A_{max}					
$0.7 \cdot A_{max}$					
$0.2 \cdot A_{max}$					

Exercise 2: Influence of Plates in the Proximity of the Coil

To be done before the lab	**Material**	**eddy current effect**	**ferromagnetic effect**
Mark the effects influencing the inductance L of the coil when the plates made of the materials listed approach the coil	**copper**		
	iron		
	PVC		

f_{res} approx. 1.5 kHz

plate material	U_C [V]	f_{res}*	$\Delta f_{res,rel}$	U_C* [V]
copper				
iron				
PVC				

material with biggest influence (highest $\Delta f_{res,rel}$)	

f_{res} approx. 10 kHz

calculated value for capacitance C ($f_{res} \approx$ 10 kHz)	
chosen value for capacitance C	
measured value of the resonant frequency f_{res}	
supply voltage U_0 at f_{res}	10 V
voltage U_C at f_{res}	

plate material	**U_C [V]**	**f_{res}***	**$\Delta f_{res,rel}$**	**U_C* [V]**
copper				
iron				
PVC				

material with biggest influence (highest $\Delta f_{res,rel}$)	

Exercise 3: Proximity Sensor

distance s	**output voltage U_A**

Lab protocol approved