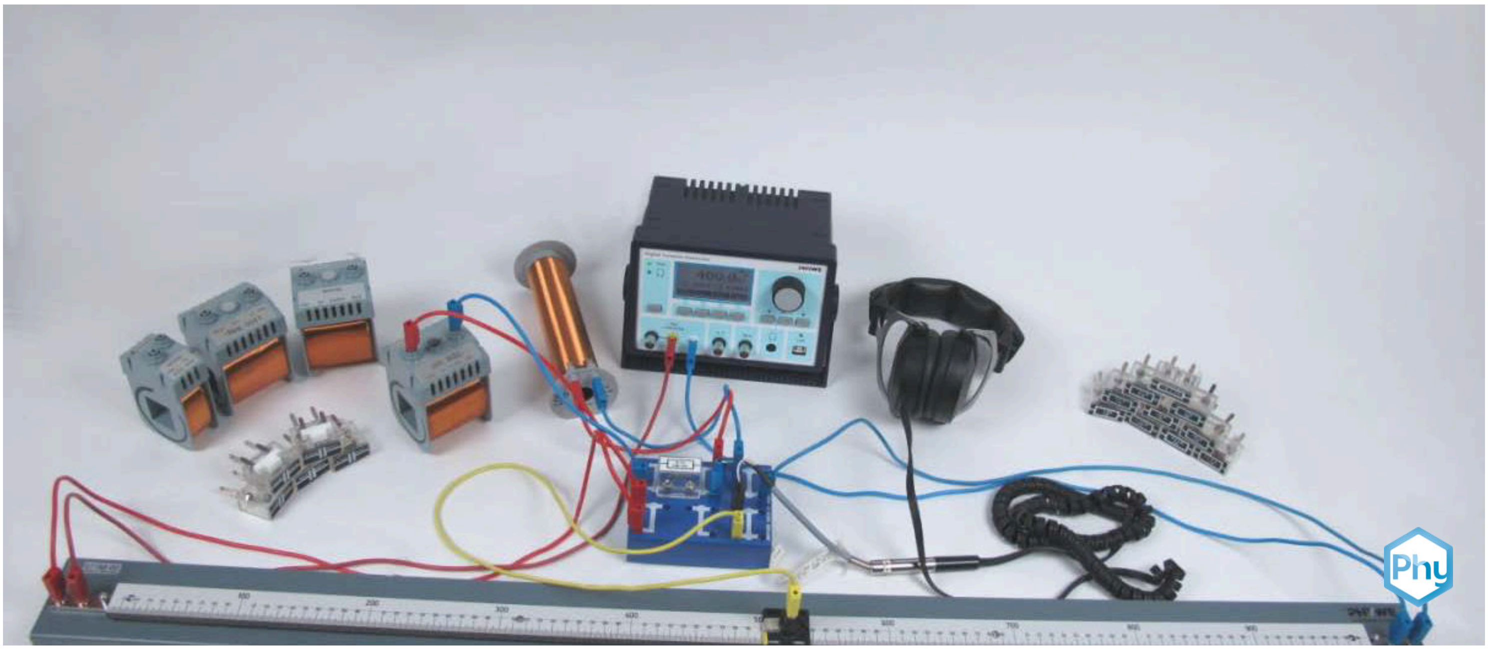
RLC measuring bridge



Physics | Electricity & Magnetism | Electronics

Applied Science | Engineering | Electrical Engineering | Properties of Electrical Circuits

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/6009d4c16080870003ab89b7

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

General information

Application

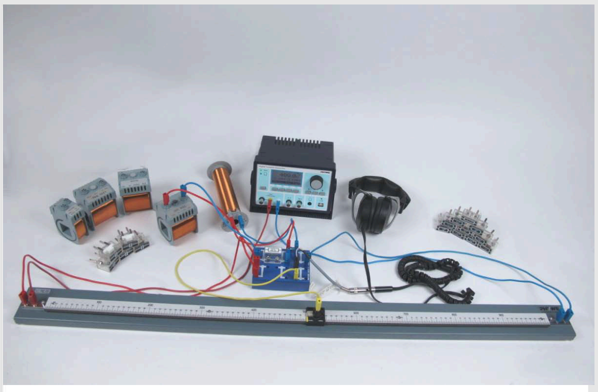


Fig. 1: Experimental set-up for determining unknown inductances

Coils, Resistors and Capacitors are a fundamental parts of electrical circuits. As such knowlege about their properties under electrical currents is importent for the understanding of their effects on such circuits.

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
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Other information (1/2)

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Prior knowledge

The prior knowledge for this experiment is found in the Theory section.

Main principle

Ohmic resistances, inductances and capacitances are determined in a Wheatstone bridge circuit operated on AC. Balancing is done aurally through headphones, using the high sensitivity of the human ear.

Other information (2/2)

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Learning objective

The goal of this experiment is to investigate the resistances, inductances and capacitances via a Wheatstone bridge circuit

Tasks

By using the Wheatstone bridge circuit, measure

1. ohmic resistances,
2. inductances and
3. capacitances.

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Theory (1/6)

In principal an unknown resistance can be determined by measuring current and voltage across the resistance. The finite intrinsic resistances of the instruments would introduce significant errors. To avoid such errors the measurement has to be done current-free.
In a Wheatstone bridge circuit the unknown resistance R_x is connected two three known resistances (see Fig. 5) of which at least one is variable. In this experiment R_1 and R_2 are adjusted in such manner that no current is flowing through the instrument G (alignment of the bridge) which means the voltage across G vanishes as well. In this case the voltages across R_x and R_1 are equal as well as across R_2 and R_3.Also, as no current is flowing through G, the same current is flowing through R_x and R_3 on the one hand (denoted as I_1)and through R_1 and R_2 on the other hand (I_2). This results into the following equations:

$I_1 R_x = I_2 R_1$ and $I_1 R_3 = I_2 R_2$

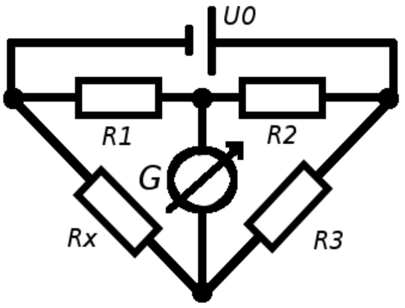

Fig. 2: Schematic circuit of the Wheatstone bridge

Theory (2/6)

Division of these relations yields eq. (4) which computes the unknown resistance R_x:

$$R_x = R_3 \cdot \frac{R_1}{R_2}$$

The voltage at the source is unimportant and may even be time-dependent. In the general bridge construction we have impedances Z_x and Z_3 instead of the resistances R_x and R_3.The current in the middle branch is zero when

$$\frac{R_1}{R_2} = \frac{Z_3}{Z_x} \quad (1)$$

In complex notation, the general form of the impedance Z is given by eq. (2) where i is the complex number, $\omega = 2\pi\nu$ is the cyclic frequency and ν is the frequency of the applied voltage.

$$Z = R + i\left(\omega L - \frac{1}{\omega C}\right) \quad (2)$$

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37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
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Theory (3/6)

Substituting into (1) gives relation (3):

$$\frac{R_1}{R_2} = \frac{R_3+i\left(\omega L_3-\frac{1}{\omega C_3}\right)}{R_x+i\left(\omega L_x-\frac{1}{\omega C_x}\right)} \quad (3)$$

The real and imaginary parts must agree on both sides. Therefore we obtain two conditions. The first is the Amplitude condition eq. (4):

$$\frac{R_1}{R_2} = \frac{R_x R_3+\left(\omega L_3-\frac{1}{\omega C_3}\right)\left(\omega L_x-\frac{1}{\omega C_x}\right)}{R_x^2+\left(\omega L_x-\frac{1}{\omega C_x}\right)} \quad (4)$$

Theory (4/6)

the second is the phase condition eq. (5):

$$R_3\left(\omega L_x-\frac{1}{\omega C_x}\right) = R_x\left(\omega L_3-\frac{1}{\omega C_3}\right) \quad (5)$$

To fulfill (5), Z_x and Z_3 must consist of components that are alike.

In the case of Z_x and Z_3 being ohmic resistances, (1) simplifies to

$$\frac{R_1}{R_2} = \frac{R_3}{R_x} \quad (6)$$

The ratio R_1/R_2 is given by the length x and the total length l of the slide wire (Fig. 2). We thus obtain the unknown resistance with relation (7)

$$R_x = R_3 \cdot \frac{x}{l-x} \quad (7)$$

where $R_1 = l - x$ and $R_2 = x$

Besides an inductive ressitance, coils also have an ohmic reactance:

$$Z_x = R_x + i\omega L_x$$

$$Z_3 = R_3 + i\omega L_3$$

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Robert-Bosch-Breite 10
37079 Göttingen
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info@phywe.de
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Theory (5/6)

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From (5) we first obtain relation (8)
$\frac{R_3}{R_x} = \frac{L_3}{L_x}$ (8)

In order to be able to fulfill this condition, we have to connect an additional resistance into the bridge branch with the coils (see Fig. 4) R_x and R_3 is then the sum of the additional resistance and the ohmic resistance of the coil in the corresponding branch. Substituting (8) into (5) we obtain

$$\frac{R_1}{R_2} = \frac{L_3}{L_x}$$

so that relation (9) holds:

$L_x = L_3 \frac{x}{l-x}$ (9)

Theory (6/6)

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The inductance of the reference coil (Art. No. 11006-01) is determined from the dimensions:

$$L_3 = 2.1 \cdot 10^{-6} \cdot N^2 \cdot r \cdot (\frac{r}{l})^{3/4}$$

where L is in H, radius r and length l are in m, and N is the number of turns. For the given coil one obtains $L_3 = 0.8$ mH.

For capacitances we obtain from relation (5)

$$\frac{R_1}{R_2} = \frac{C_4}{C_3}$$

and thus

$C_x = C_3 \frac{l-x}{x}$ (10)

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Robert-Bosch-Breite 10
37079 Göttingen

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Equipment

Position	Material	Item No.	Quantity
1	PHYWE Digital Function Generator, USB	13654-99	1
2	Slide wire measurement bridge	07182-00	1
3	Headphone, stereo	65974-00	1
4	Coil, 300 turns	06513-01	1
5	Coil, 600 turns	06514-01	1
6	Coil, 1200 turns	06515-01	1
7	Coil, 600 turns, short	06522-01	1
8	Induction coil,300 turns,dia.40mm	11007-01	1
9	Resistor 1 Ohm 2%, 2W, G1	06055-10	1
10	Resistor 2 Ohm 5%, 2W, G1	06055-20	1
11	Resistor 5 Ohm 2%, 2W, G1	06055-50	1
12	Resistor 10 Ohm 2%, 2W, G1	06056-10	1
13	Resistor 330 Ohm, 1W, G1	39104-13	1
14	Resistor 470 Ohm, 1W, G1	39104-15	1
15	Resistor 680 Ohm, 1W, G1	39104-17	1
16	Resistor 1 kOhm, 1W, G1	39104-19	2
17	Resistor 1,5 kOhm, 1W, G1	39104-21	1
18	Resistor 2.2 kOhm, 1W, G1	39104-23	1
19	Resistor 3.3 kOhm, 1W, G1	39104-25	1
20	Capacitor 100pF/100V, G1	39105-04	1
21	Capacitor 470pF/100V, G1	39105-07	1
22	Capacitor 1nF/ 100V, G1	39105-10	1
23	Capacitor 47nF/ 250V, G1	39105-17	1
24	Capacitor 10nF/ 250V, G1	39105-14	1
25	Capacitor 100 nF/250V, G1	39105-18	1
26	Connection box	06000-00	1
27	Connecting cord, 32 A, 250 mm, red	07360-01	2
28	Connecting cord, 32 A, 250 mm, blue	07360-04	2
29	Connecting cord, 32 A, 750 mm, red	07362-01	2
30	Connecting cord, 32 A, 750 mm, yellow	07362-02	1
31	Short-circuit plug, white	06027-06	2
32	Connecting cord, 32 A, 750 mm, blue	07362-04	2
33	Headphone Adapter jack plug/2 x 4 mm plug	65974-01	1

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Robert-Bosch-Breite 10
37079 Göttingen

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Setup and Procedure

Setup (1/2)

- Set up the experiment according to Fig. 1 and the respective schematic in Fig. 3–5. the digital frequency generator is connected in parallel to the measuring bridge. For the measurement of resistances use the resistance of 1.0 kΩ (39104-19) as reference. For the measurement of the inductances the variable resistance is needed to compensate for the different DC resistances in the coils. Use the induction coil (11006-01) as reference. The Headphone is used instead of an Ampère-meter to balance the Wheatstone circuit.

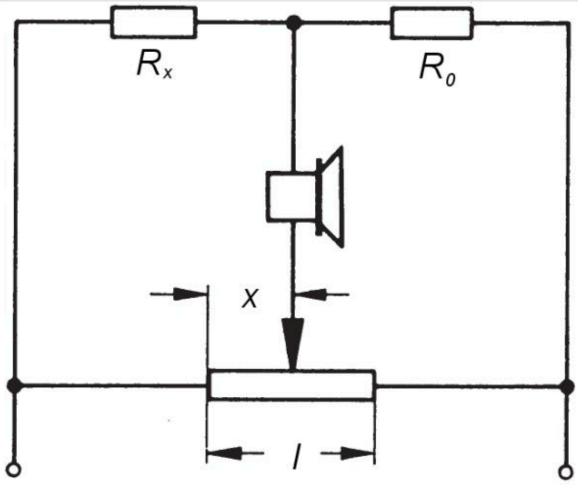

Fig. 3: Schematic circuit for task 1 (ohmic resistances).

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37079 Göttingen
Tel.: 0551 604 - 0
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Setup (2/2)

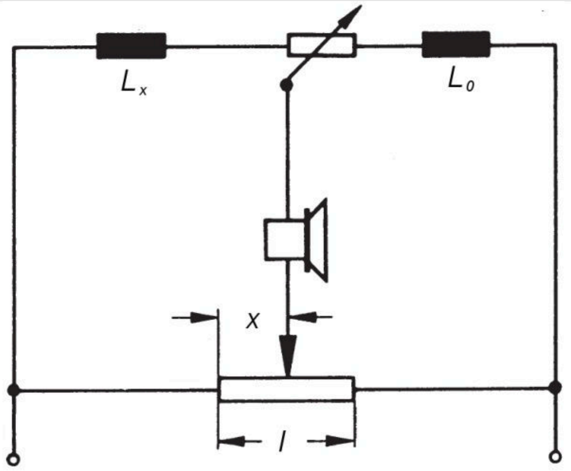

Fig. 4: Schematic circuit for task 2 (inductances).

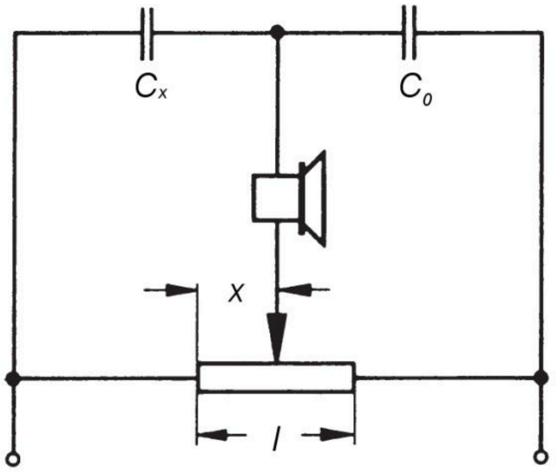

Fig. 5: Schematic circuit for task 3 (cpacitances).

Procedure

- Choose a frequency on the frequency generator that is suited for the measurements, e.g. 400 Hz. Tune the amplitude to no more than 1 V before putting on the headphones. In case of the measurement of inductances, try and find that resistance R_P for which the sound at a given slide position is lowest. Move the slide into each direction until the sound minimizes or disappears entirely. Especially for the inductance measurement, only a range can be determined, for which the sound is lowest. Try to determine that range as carefully as possible and note down the medium point of that range as the distance with lowest amplitude. When the sound amplitude becomes too low to hear, tune up the voltage output to a maximum of 20 V. Do not forget to tune it down as soon as you have found the balancing point and before changing any part of the circuit. Do not switch resistances/coils/capacitances while having such a high signal amplitude with headphones on – you are in danger of damaging your eardrums seriously!

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Robert-Bosch-Breite 10
37079 Göttingen
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Evaluation

Task 1

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In the following the evaluation of the obtained values is described with the help of example values. Your results may vary from those presented here. For Task 1, reference resistance 1.0 kΩ was used. In Tab. 1 the measured values are shown and the calculated resistances are compared to the expected values. Most values compare quite well, only the values for Art. No. 39104-21 deviate from the expectation.

Resistor (Art. No.)	**x [mm]**	R_x **[Ω] (calc.)**	R_x **[Ω] (theo.)**
39104-13	244	323	330
39104-15	317	464	470
39104-17	402	672	680
39104-19	502	1008	1000
39104-21	616	1604	1500
39104-23	688	2205	2200
39104-25	768	3310	3300

Tab. 1: Measured and calculated values for Task 1.

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Task 2

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In Tab. 2 the measured values of Task 2 are shown and the calculated inductances are compared to the expected values. The values compare quite well.

Inductance (Art. No.)	x [mm]	R_P [Ω]	L_x [mH] (calc.)	L_x [mH] (theo.)
06513-01	620	1	1.3	2
06514-01	920	2	9.2	9
06515-01	975	10	31.2	35
06522-01	950	5	15.2	15

Tab. 2: Measured and calculated values for Task 2. R_P denotes the additional resistance that compensates the coil's DC resistance.

Task 3

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For Task 3 the capacitance of 1 nF (39105-10) had been used as reference. The measured values are shown in Tab. 3 as well as calculated and expected capacitances. The experimental values compare very well with theoretical values.

Capacitance (Art. No.)	x [mm]	C_x [nF] (calc.)	C_x [nF] (theo.)
39105-04	910	0.10	0.1
39105-07	680	0.47	0.47
39105-14	100	9.00	10
39105-18	5	99.00	100

Tab. 3: Measured and calculated values for Task 3.

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
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