

Voltage and current transformation with a transformer

Objects of the experiment

- Measuring the secondary voltage of an unloaded transformer as function of the primary voltage for several ratios of windings between primary and secondary coil.
- Measuring the secondary current of a transformer in short-circuit operation as function of the primary current for several ratios of windings between primary and secondary coil.
- Demonstration of an isolating transformer and an autotransformer

Principles

A transformer usually consists of two coils which are inductively coupled by an iron core. Transformers are used to change the voltage amount of alternating currents. The frequency of the voltage is not changed by the conversion.

The input lines connect to the 'primary' coil, while the output lines connect to the 'secondary' coil. The alternating current in the primary coil induces an alternating magnetic flux that 'flows' around the ferromagnetic core. The alternating flux in the core in turn induces an alternating current in the secondary coil.

Regardless of the physical design of the transformer the voltage transformation of an 'ideal' transformer *without load* is determined by the ratio of the respective number of turns:

$$\frac{U_2}{U_1} = \frac{N_2}{N_1} \quad (\text{when } I_2 = 0) \quad (\text{I})$$

U_1 : voltage of primary coil

U_2 : voltage of secondary coil

N_1 : number of turns of primary coil

N_2 : number of turns of secondary coil

The current transformation in *short-circuit* operation of an 'ideal' transformer is inversely proportional to the ratio of the number of turns:

$$\frac{I_2}{I_1} = \frac{N_1}{N_2} \quad (\text{when } U_2 = 0) \quad (\text{II})$$

I_1 : current of primary coil

I_2 : current of secondary coil

The properties of the transformer under load, on the other hand, depends on its particular physical design. The secondary voltage behaviour of various transformer designs under load is investigated in experiment P3.4.5.2.

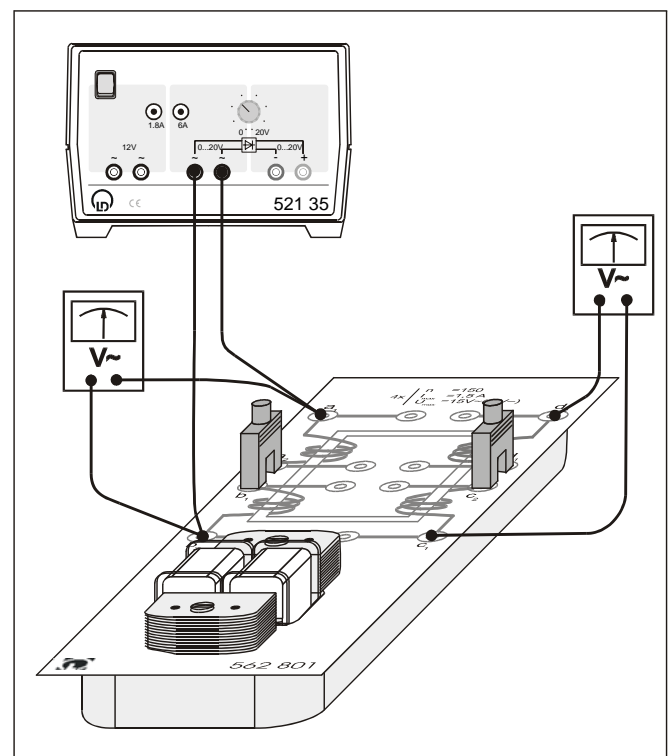


Fig. 1: Experimental setup to investigate the voltage transformation of an unloaded transformer.

In this experiment the voltage and current transformation is measured for a 'soft' transformer (i.e. primary and secondary coil on separate limbs) without load. The difference between an isolating transformer and an autotransformer is demonstrated.

Apparatus

1 Transformer for student's experiments	562 801
1 Variable extra low-voltage transformer S.....	521 35
2 Multimeter LD analog 20.....	531 120
6 Connecting lead 100 cm black.....	500 444

Carrying out the experiment

a) voltage transformation (secondary-side without load)

- Connect the low voltage power supply, and the voltmeters as shown in Fig. 1. It is recommended to start with the ratio $N_1 : N_2$ of 300 : 150 as depicted in setup b) of Fig. 2.
- Vary the voltage U_1 between 0 V and 10 V and measure the voltage U_2 .
- Repeat this experiment for ratio of the number of turns $N_1 : N_2 = 150 : 300$ of the primary and secondary windings (setup c) of Fig. 2).
- Repeat this experiment for ratio of the number of turns $N_1 : N_2 = 300 : 300$ of the primary and secondary windings (setup a) of Fig. 2).

Safety notes

Increase AC voltages on the transformer only gradually; do not apply higher voltages directly! (danger of damage to connected measuring instruments due to high currents – 100-fold excess currents).

Avoid overheating of the transformer – Mind the maximum applied voltages and currents listed on the base panel and in the instruction sheet 562 801 of the transformer for student's experiments.

- Maximum permissible AC voltage per winding 15 V AC.
- Maximum permissible power consumption 40 W.

Setup

a) voltage transformation (secondary-side without load)

Set up the transformer, the variable low voltage power supply and the voltmeter according Fig. 1. Setups for various combination of turns of the primary and secondary coil are shown in Fig. 2.

b) current transformation (secondary-side short-circuit)

Setups for various combination of turns of the primary and secondary coil are shown in Fig. 3.

c) isolating transformer and an autotransformer

A schematic representation of the setup for an isolating transformer is shown in Fig. 4 A).

Note: There is no conductive connection between the primary and secondary coils, i.e. a_1 and d_1 or a_2 and d_2 are not connected.

A schematic representation of the setup for an autotransformer is shown in Fig. 4 B).

Note: The secondary coil is formed by a part of the primary coil at the same time.

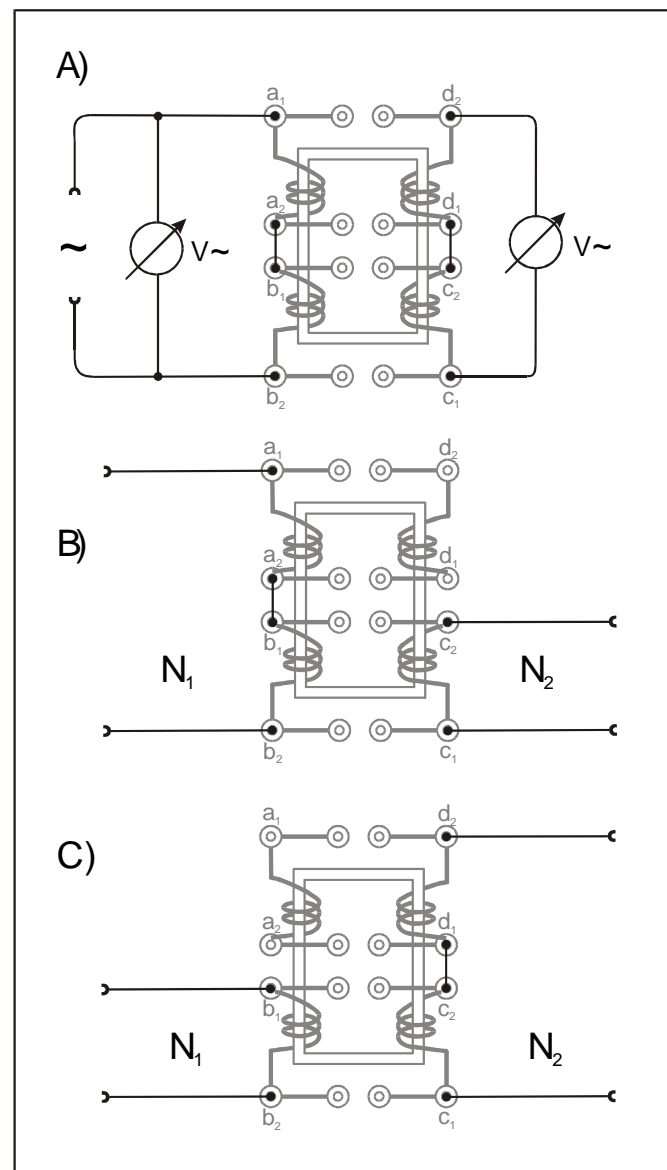


Fig. 2: Voltage transformation: Schematic representation of the experimental setup (wiring diagram) for measuring the secondary voltage U_2 as function of the primary voltage U_1 for various ratios of the number of turns of the primary and secondary windings
 A) $N_1 : N_2 = 300 : 300$,
 B) $N_1 : N_2 = 300 : 150$,
 C) $N_1 : N_2 = 150 : 300$.

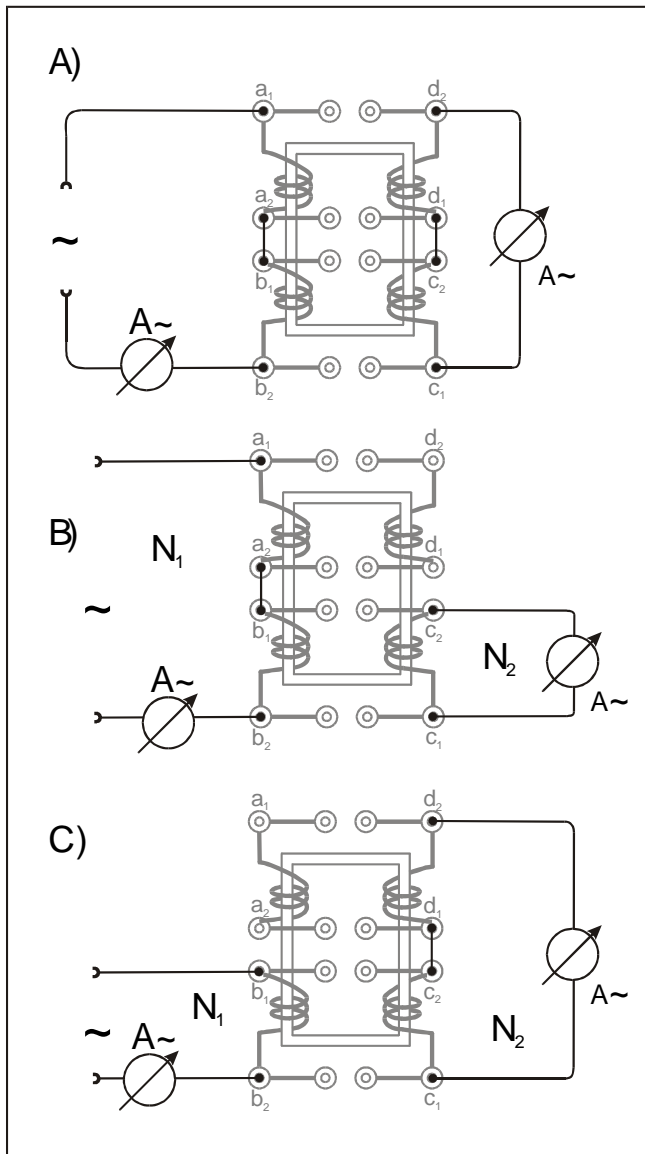


Fig. 3: Current transformation: Schematic representation of the experimental setup (wiring diagram) for measuring the secondary current I_2 as function of the primary current I_1 for various ratios of the number of turns of the primary and secondary windings

- A) $N_1 : N_2 = 300 : 300$,
 B) $N_1 : N_2 = 300 : 150$,
 C) $N_1 : N_2 = 150 : 300$.

c) isolating transformer and autotransformer

- Setup an isolating transformer with ratio of the number of turns $N_1 : N_2 = 150 : 150$ as shown in a) of Fig. 4.

Note: There is no conducting connection between primary and secondary coils. Thus all transformers depicted in Fig. 2 and Fig. 3 are isolating transformers.

- Vary the voltage U_1 between 0.1 and 10 V and observe the change of the voltage U_2 .
- Setup an autotransformer with ratio of the number of turns $N_1 : N_2 = 300 : 150$ as shown in b) of Fig. 4.
- Vary the voltage U_1 between 0.1 and 10 V and observe the change of the voltage U_2 .

b) current transformation (secondary-side short-circuit)

- Connect the low voltage power supply, and the ammeters to the Transformer for student's experiments as shown in the wiring diagram a) of Fig. 3. It is recommended to start with the ratio $N_1 : N_2$ of 300 : 150 as depicted in setup b) of Fig. 3.
- Vary the current I_1 between 0.1 A and approximately 1.0 A and measure the current I_2 .

Note: The maximum value of $I_{max} = 1.5$ A should not be exceeded for I_2 . Watch the ammeters indicating I_2 when setting the current I_1 .

- Repeat this experiment for ratio of the number of turns $N_1 : N_2 = 150 : 300$ of the primary and secondary windings (setup c) of Fig. 2).
- Repeat this experiment for ratio of the number of turns $N_1 : N_2 = 300 : 300$ of the primary and secondary windings (setup a) of Fig. 2).

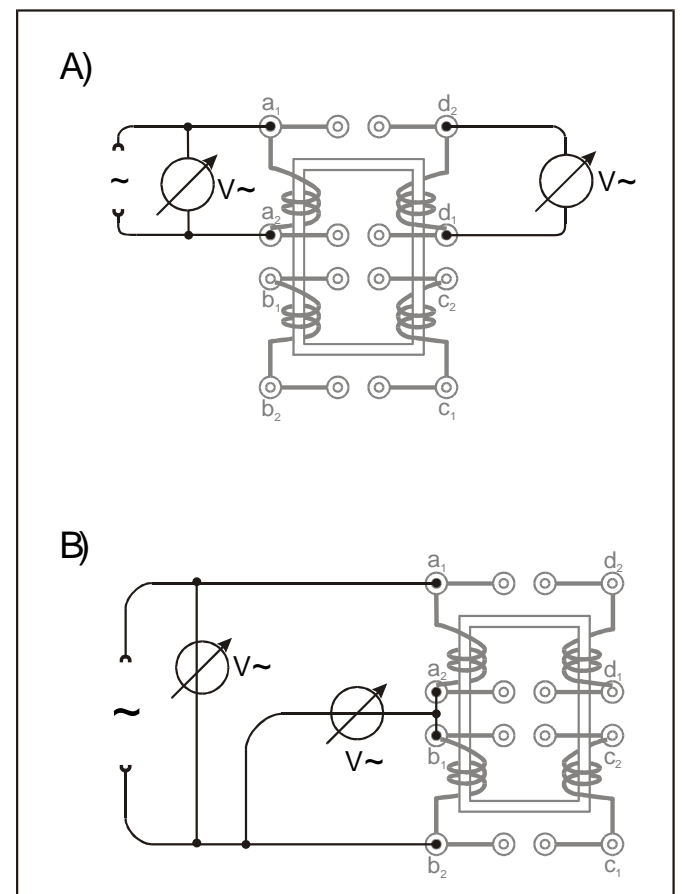


Fig. 4: A) Wiring diagram for investigation of an isolating transformer with the ratio $N_1 : N_2 = 150 : 150$.

- B) Wiring diagram for investigation of an autotransformer with the ratio $N_1 : N_2 = 300 : 150$.

Measuring example

a) voltage transformation (secondary-side without load)

Table. 1: Voltage U_2 as function of voltage U_1 for various ratios of number of turns $N_1:N_2$.

$\frac{U_1}{V}$	$\frac{U_2}{V} \left(\frac{N_1}{N_2} = \frac{300}{150} \right)$	$\frac{U_2}{V} \left(\frac{N_1}{N_2} = \frac{300}{300} \right)$	$\frac{U_2}{V} \left(\frac{N_1}{N_2} = \frac{150}{300} \right)$
1.0	0.4	1.0	2.0
2.0	0.9	2.0	4.0
3.0	1.4	3.0	6.0
4.0	1.9	3.9	8.0
5.0	2.4	5.0	9.9
6.0	2.9	5.9	-
7.0	3.4	6.9	-
8.0	4.0	8.0	-
9.0	4.5	9.0	-
10.0	5.0	10.0	-

b) current transformation (secondary-side short-circuit)

Table. 2: Current I_2 as function of current I_1 for various ratios of number of turns $N_1:N_2$.

$\frac{I_1}{A}$	$\frac{I_2}{A} \left(\frac{N_1}{N_2} = \frac{300}{150} \right)$	$\frac{I_2}{A} \left(\frac{N_1}{N_2} = \frac{300}{300} \right)$	$\frac{I_2}{A} \left(\frac{N_1}{N_2} = \frac{150}{300} \right)$
0.1	0.21	0,10	0.05
0.2	0.41	0,20	0.01
0.3	0.60	0,30	0.15
0.4	0.79	0,39	0.20
0.5	0.98	0,49	0.25
0.6	1.20	0,59	0.29
0.7	1.40	0,69	0.35
0.8	-	0,79	0.39
0.9	-	0,89	0.45
1.0	-	0,98	0.49

Evaluation and Results

a) voltage transformation (secondary-side without load)

From Table 1 and Fig. 5. follows that input voltage is proportional the output voltage:

$$U_1 \sim U_2$$

The relationship between primary and secondary voltage of an unloaded transformer is the same as the relationship between the number of turns of primary and secondary coils:

$$\frac{U_2}{U_1} = \frac{N_2}{N_1}$$

For $N_1 = N_2$ the primary and secondary voltage is the same.

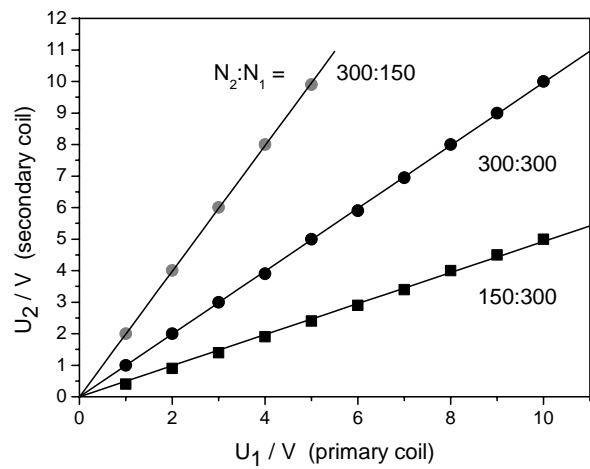


Fig. 5: Secondary voltage U_2 as function of the primary voltage U_1 for different ratios of number of turns $N_2 : N_1$. The straight lines correspond to a fit according equation (I).

b) current transformation (secondary-side short-circuit)

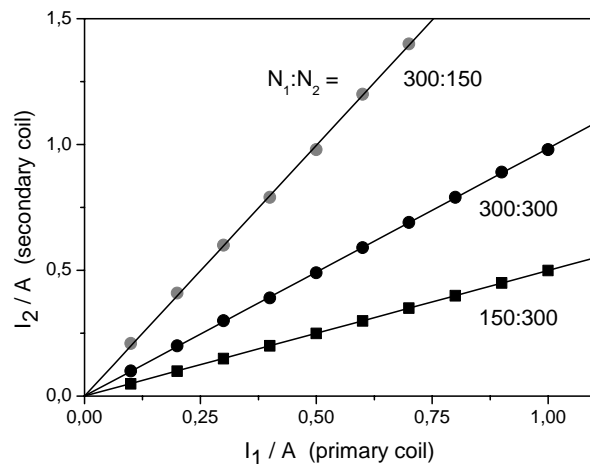


Fig. 6: Secondary current I_2 as function of the primary current I_1 for different ratios of number of turns $N_1 : N_2$. The straight lines correspond to a fit according equation (II).

From Table 2 and Fig. 6 follows that current of the primary side is proportional to the current on the secondary side:

$$I_1 \sim I_2$$

The relationship between the primary and secondary current of a transformer in short-circuit operation is inverse to the relationship between the number of turns of the primary and secondary coil:

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

For $N_1 = N_2$ the current in the primary and secondary coils are the same.

c) isolating transformer and autotransformer

Using the ratio $N_1 : N_2 = 150:150$ (or $300:300$) the voltage of the isolated transformer is transformed according:

$$U_2 \sim U_1$$

Using the ratio $N_1 : N_2 = 300:150$ the voltage of the autotransformer is transformed according:

$$\frac{U_2}{U_1} = \frac{N_2}{N_1} = \frac{1}{2}$$

In this experiment the transformer is used to isolate two AC circuits electrically. There is no conductive connection between the primary and the secondary coils; both coils are coupled by the magnetic field. Therefore an earth free voltage source is available on the secondary side whose outputs can be arbitrarily earthed if required. This gives this type of transformer the name isolating transformer.

The setup b) in Fig. 4, i.e. the autotransformer, is a different type of transformer where electrical isolation does not occur because of a part of the windings on one core forms the primary and secondary coil at the same time. For this reason the transformer is also called one-coil transformer. This transformer type can be used as voltage converter only. In comparison to the isolating transformer the material savings of copper and iron can be significant if the difference between input and the output voltage is small.

Supplementary information

A transformer may have multiple secondary coils to feed a number of electrical loads; however, power must be conserved, so the sum of the output power must equal the sum of the input power minus losses.

Energy losses in transformers are due to a number of factors: these are copper losses in the coils themselves due to material resistance, core losses due to hysteresis (the reluctance of the material's magnetic domains to reverse during each electrical cycle), and eddy currents.

