Principles of Electric Circuits

Chapter 14

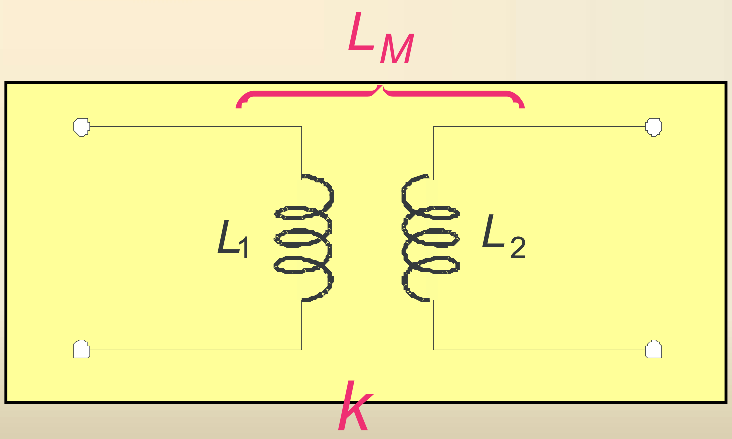
Chapter 14

Summary

Mutual Inductance

When two coils are placed close to each other, a changing flux in one coil will cause an induced voltage in the second coil. The coils are said to have **mutual inductance** (L_M), which can either add or subtract from the total inductance depending on if the fields are aiding or opposing.

The coefficient of coupling is a measure of how well the coils are linked; it is a number between 0 and 1.



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Summary

Mutual Inductance

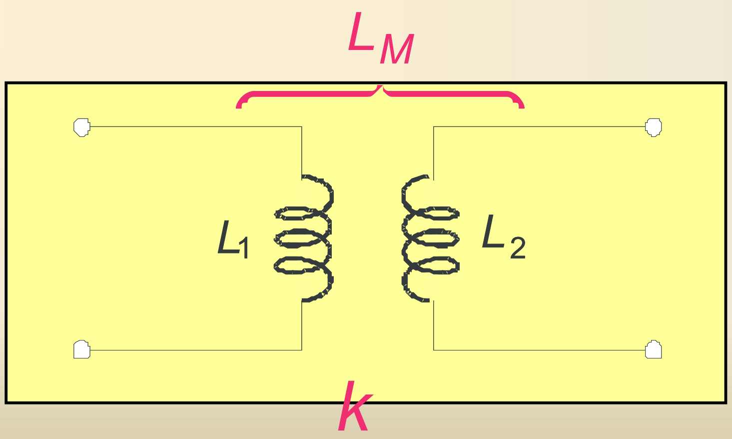
The formula for mutual inductance is

$$L_M = k\sqrt{L_1 L_2}$$

k = the coefficient of coupling (dimensionless)

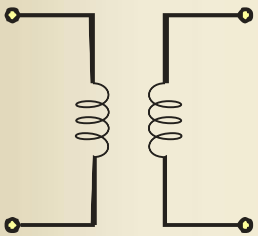
L_1, L_2 = inductance of each coil (H)

The coefficient of coupling depends on factors such as the orientation of the coils to each other, their proximity, and if they are on a common core.

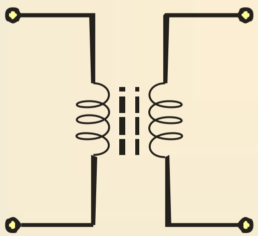


Basic Transformer

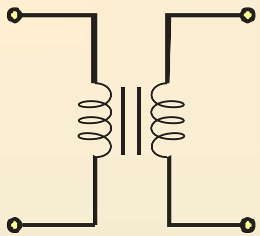
The basic transformer is formed from two coils that are usually wound on a common core to provide a path for the magnetic field lines. Schematic symbols indicate the type of core.



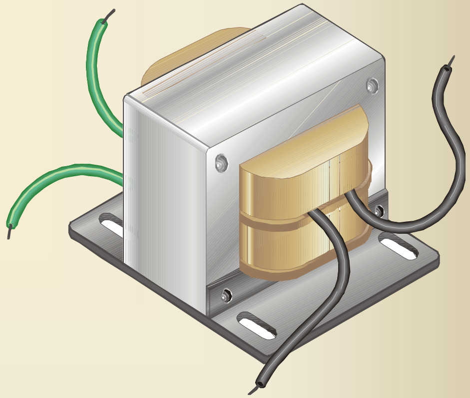
Air core



Ferrite core



Iron core



Small power transformer

Summary

Turns ratio

A useful parameter for ideal transformers is the turns ratio defined* as

$$n = \frac{N_{sec}}{N_{pri}}$$

N_{sec} = number of secondary windings

N_{pri} = number of secondary windings

* Based on the IEEE dictionary definition for electronics power transformers.

Most transformers are not marked with turns ratio, however it is a useful parameter for understanding transformer operation.

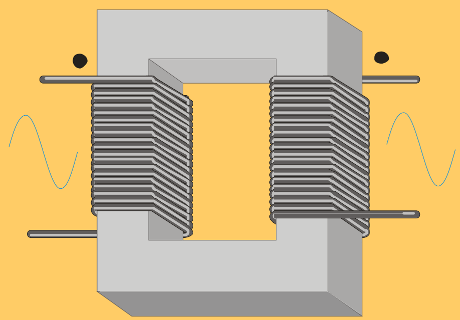
Example

A transformer has 800 turns on the primary and a turns ratio of 0.25. How many turns are on the secondary? 200

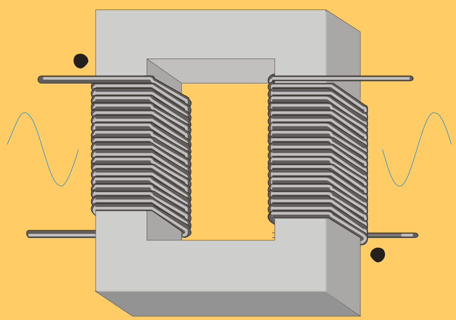
Summary

Direction of windings

The direction of the windings determines the polarity of the voltage across the secondary winding with respect to the voltage across the primary. Phase dots are sometimes used to indicate polarities.



In phase



Out of phase

Summary

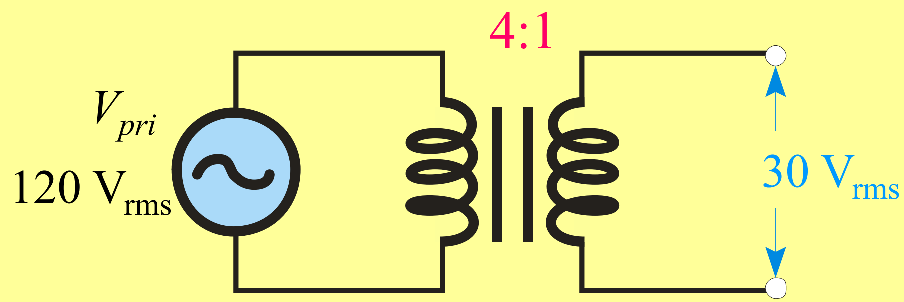
Step-up and step-down transformers

In a **step-up transformer**, the secondary voltage is greater than the primary voltage and $n > 1$.

In a **step-down transformer**, the secondary voltage is less than the primary voltage and $n < 1$.

Example

What is the secondary voltage?



What is the turns ratio? 0.25

Summary

Isolation transformers

A special transformer with a turns ratio of 1 is called an **isolation transformer**. Because the turns ratio is 1, the secondary voltage is the same as the primary voltage, hence ac is passed from one circuit to another.

The purpose of an isolation transformer is to break a dc path between two circuits while maintaining the ac path. The DC is blocked by the transformer, because the magnetic flux is not changing.

Summary

Current

Transformers cannot increase power. If the secondary voltage is higher than the primary voltage, then the secondary current must be lower than the primary current and vice-versa.

The ideal transformer turns ratio equation for current is

$$n = \frac{I_{pri}}{I_{sec}}$$

Notice that the primary current is in the numerator.

Summary

Power

The ideal transformer does not dissipate power. Power delivered from the source is passed on to the load by the transformer. This important idea can be summarized as

$$P_{pri} = P_{sec}$$

$$V_{pri}I_{pri} = V_{sec}I_{sec}$$

$$\frac{V_{sec}}{V_{pri}} = \frac{I_{pri}}{I_{sec}}$$

← These last ratios are, of course, the turns ratio, *n*.

Summary

Reflected resistance

A transformer changes both the voltage and current on the primary side to different values on the secondary side. This makes a load resistance appear to have a different value on the primary side.

From Ohm's law, $R_{pri} = \frac{V_{pri}}{I_{pri}}$ and $R_L = \frac{V_{sec}}{I_{sec}}$

Taking the ratio of R_{pri} to R_L,

$$\frac{R_{pri}}{R_L} = \left(\frac{V_{pri}}{V_{sec}}\right)\left(\frac{I_{sec}}{I_{pri}}\right) = \left(\frac{1}{n}\right)\left(\frac{1}{n}\right) = \frac{1}{n^2}$$

Summary

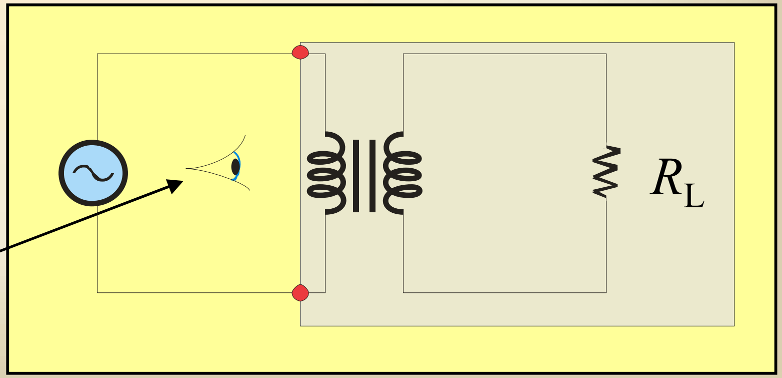
Reflected resistance

The resistance "seen" on the primary side is called the **reflected resistance**.

$$R_{pri} = \left(\frac{1}{n}\right)^2 R_L$$

If you "look" into the primary side of the circuit, you see an effective load that is changed by the reciprocal of the turns ratio squared.

You see the primary side resistance, so the load resistance is effectively changed.



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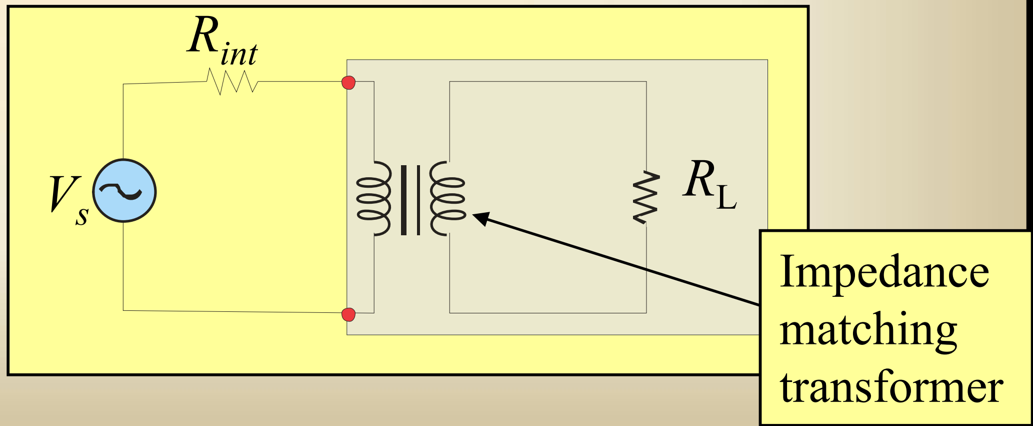
Summary

Impedance matching

The word *impedance* is used in ac work to take into account resistance and reactance effects. To match a load resistance to the internal source resistance (and hence transfer maximum power to the load), a special impedance matching transformer is used.

Impedance matching transformers are designed for a wider range of frequencies than power transformers, hence tend to be not ideal.



Summary

Non-ideal transformers

An ideal transformer has no power loss; all power applied to the primary is all delivered to the load. Actual transformers depart from this ideal model. Some loss mechanisms are:

Winding resistance (causing power to be dissipated in the windings.)

Hysteresis loss (due to the continuous reversal of the magnetic field.)

Core losses due to circulating current in the core (eddy currents).

Flux leakage flux from the primary that does not link to the secondary

Winding capacitance that has a bypassing effect for the windings.

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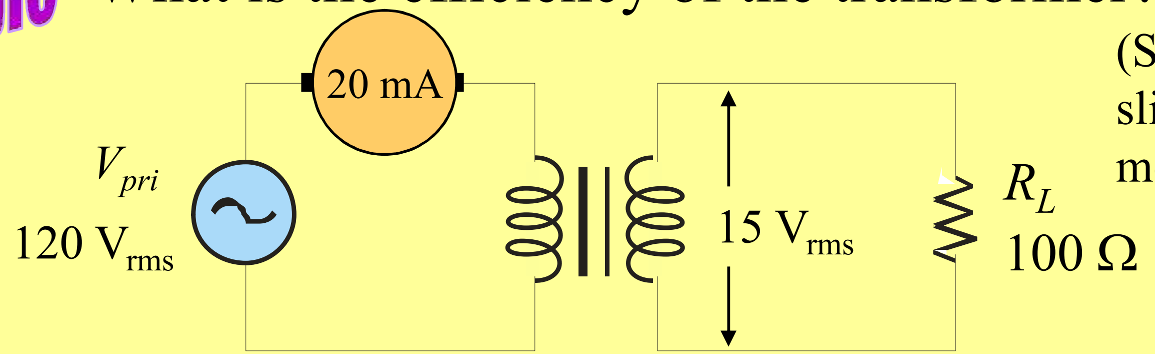
Summary

Transformer efficiency

The efficiency of a transformer is the ratio of power delivered to the load (P_{out}) to the power delivered to the primary (P_{in}). Than is

$$\eta = \left(\frac{P_{out}}{P_{in}}\right)100\%$$

Example What is the efficiency of the transformer? 94%



(See next slide for method.)

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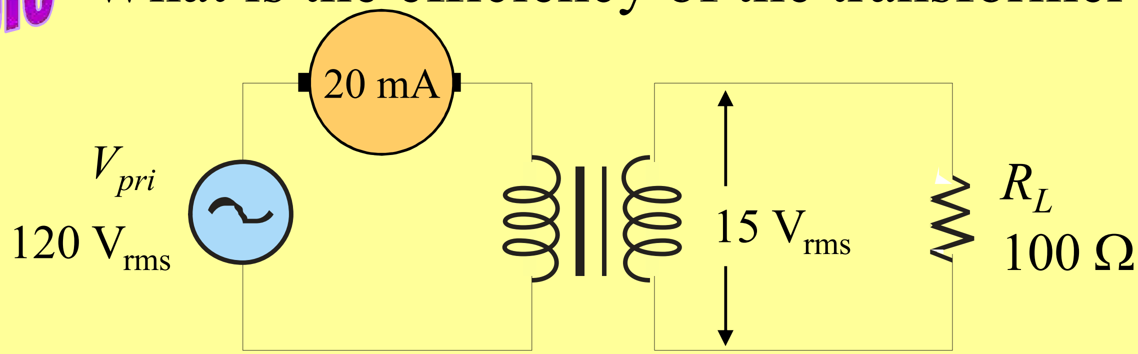
Summary

Transformer efficiency

$$\eta = \left(\frac{P_{out}}{P_{in}}\right)100\% = \left(\frac{V_L^{\,2}/R_L}{(V_{pri})(I_{pri})}\right)100\% = \left(\frac{15\ \text{V}^2/100\ \Omega}{(120\ \text{V})(0.020\ \text{A})}\right)100\% = 94\%$$

Example What is the efficiency of the transformer? 94%

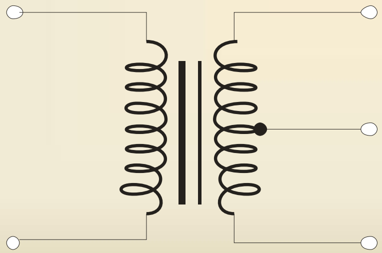


Summary

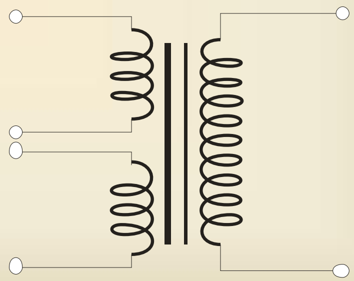
Tapped and multiple-winding transformers

Frequently, it is useful to tap a transformer to allow for a different reference or to achieve different voltage ratings, either on the primary side or the secondary side.

Multiple windings can be on either the primary or secondary side. One application for multiple windings is to connect to either 110 V or 220 V operation.



Secondary with center-tap



Primary with multiple-windings

Selected Key Terms

Mutual inductance The inductance between two separate coils, such as in a transformer.

Transformer An electrical device constructed of two or more coils that are magnetically coupled to each other so that there is mutual inductance from one coil to the other.

Primary winding The input winding of a transformer; also called *primary*.

Secondary winding The output winding of a transformer; also called *secondary*.

Selected Key Terms

Magnetic coupling The magnetic connection between two coils as a result of the changing magnetic flux lines of one coil cutting through the second coil.

Turns ratio The ratio of the turns in the secondary winding to the turns in the primary winding.

Reflected resistance The resistance of the secondary circuit reflected into the primary circuit.

Impedance matching A technique used to match a load resistance to a source resistance in order to achieve maximum transfer of power.

Quiz

1. The measurement unit for the coefficient of coupling is

   a. ohm

   b. watt

   c. meter

   d. dimensionless

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Quiz

2. A step-up transformer refers to one in which

a. The voltage across the secondary is higher than the primary.

b. The current in secondary is higher than the primary.

c. The power to the load is higher than deleivered to the primary

d. All of the above

Quiz

3. An isolation transformer

a. blocks both ac and dc

b. blocks ac but not dc

c. blocks dc but not ac

d. passes both ac and dc

Quiz

4. If the *current* in the secondary is higher than in the primary, the transformer is a

a. a step-up transformer

b. an isolation transformer

c. a step-down transformer

d. not enough information to tell

Quiz

5. An ideal transformer has

a. no winding resistance

b. no eddy current loss

c. power out = power in

d. all of the above

Quiz

6. Assume a step-down transformer is used between a source and a load. From the primary side, the load resistance will appear to be

a. smaller

b. the same

c. larger

Quiz

7. A transformer that can deliver more power to the load than it receives from the source is a(n)

a. step-up type

b. step-down type

c. isolation type

d. none of the above

Quiz

8. Generally, the purpose of an impedance matching transformer is to

a. make the load voltage appear to be the same as the source voltage

b. make the load resistance appear to be the same as the source resistance

c. make the load current appear to be the same as the source current

d. provide more power to the load than is delivered from the source

Quiz

9. A type of transformer that tends to not be ideal because it is designed for a good frequency response is a

a. step-up type

b. step-down type

c. isolation type

d. impedance matching type

Quiz

10. A transformer that could be used for 110 V or 220 V operation is a

a. multiple-winding type

b. center-tapped type

c. isolation type

d. all of the above

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Quiz

Answers:

1. d
2. a
3. c
4. c
5. d
6. c
7. d
8. b
9. d
10. a