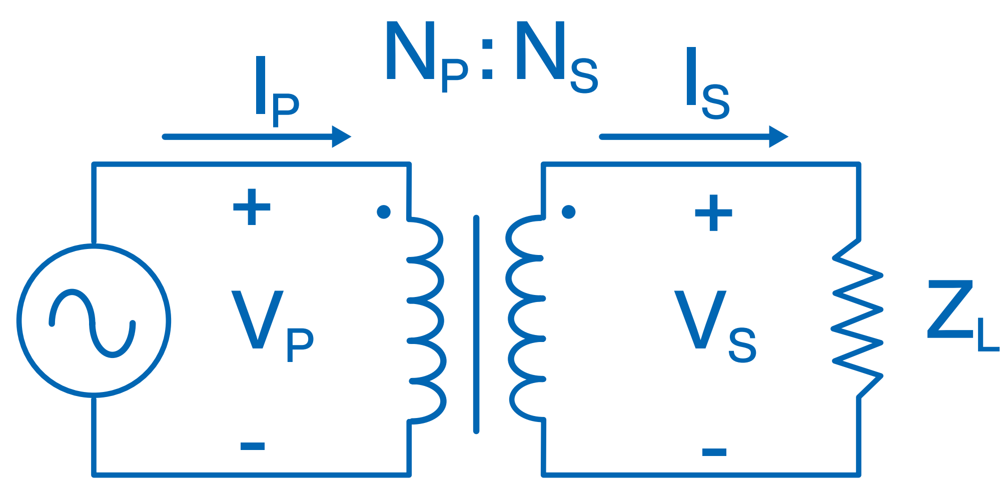
Transformers Reference Guide

Transformers

A transformer consists basically of coil windings made of conductive material, surrounding a metal core. A varying current in any one coil of the transformer produces a varying magnetic flux in the transformer's core, which induces a varying electromotive force across other coils. Electrical energy can be transferred between separate coils without a conductive connection between the two circuits.

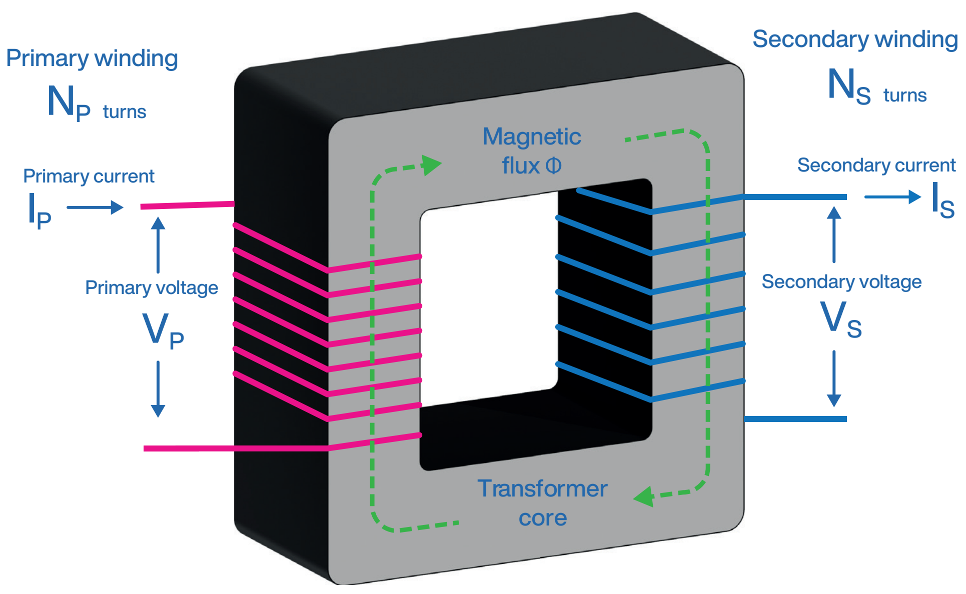
- Are passive components
- Transfer electrical energy between electrical circuits (coils)
- Obey Faraday's law of induction



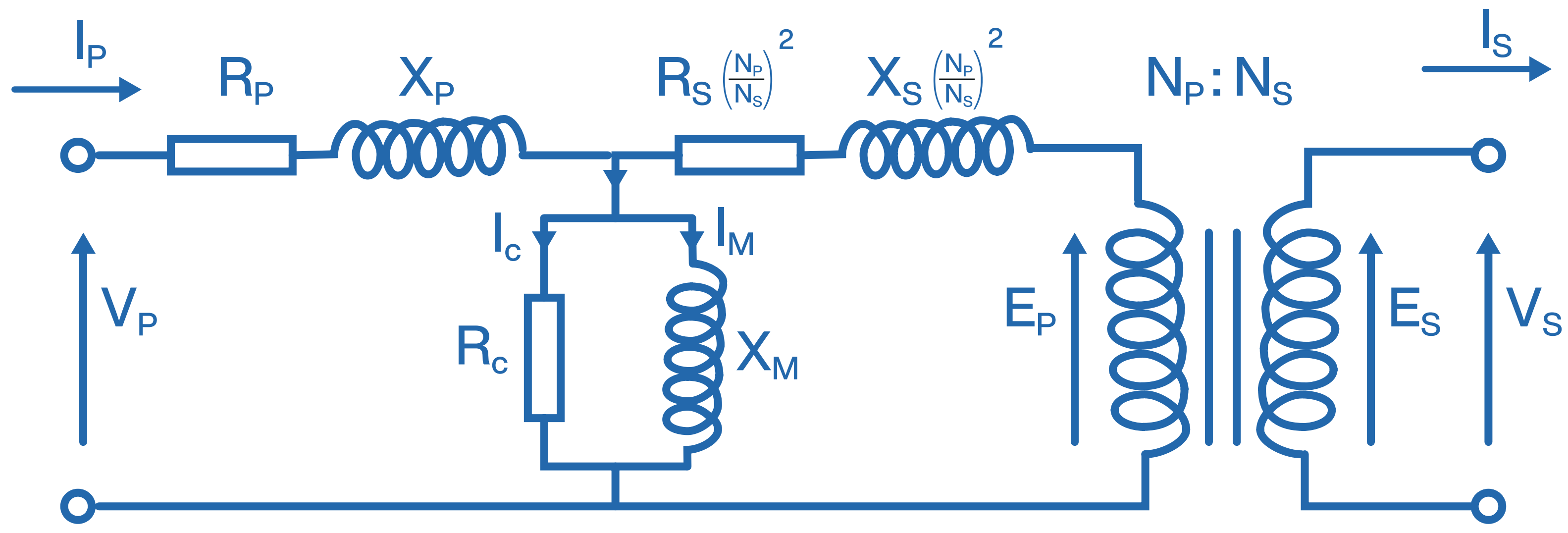
Key

- N_P : Number of windings on primary coil
- N_S : Number of windings on secondary coil
- V_P : Instantaneous Voltage on primary coil (source)
- V_S : Instantaneous Voltage on secondary coil
- I_P : Current on primary coil
- I_S : Current on secondary coil
- Z_L : Load impedance
- Φ : Magnetic Flux through one turn of the winding
- L : Winding self-inductance

Ideal transformer



Taking these real-world issues into account, the equivalent circuit looks like this:



Winding joule losses and leakage reactances are approximated by loop impedances R_P, R_S and X_P, X_S. Core losses: R_C and X_M (magnetizing reactance).

Equations

$$V_P = -N_P \frac{d\Phi}{dt}$$

$$V_S = -N_S \frac{d\Phi}{dt}$$

Turns ratio $a = \frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P} = \sqrt{\left(\frac{L_P}{L_S}\right)}$

a>1 : Step-down transformer

a<1 : Step-up transformer

a=1 : Isolation transformer

Real-world transformers have to deal with :

Core Losses:

- Nonlinear magnetic effects in the core cause Hysteresis Losses
- Heating of the core causes Eddy Current Losses

Winding Losses:

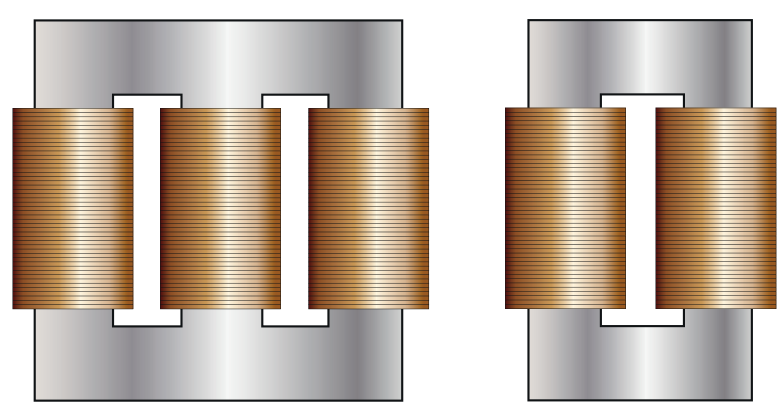
- Resistance and inductance in the winding material cause Joule Losses
- Reactive impedance is caused by leakage flux

Parasitic Capacitance:

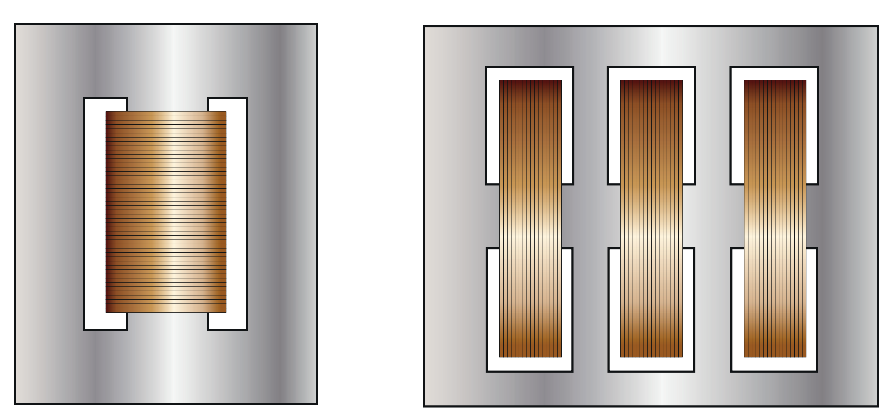
- Capacitance between adjacent winding layers
- Capacitance between adjacent turns in one winding layer
- Capacitance between Core and adjacent winding layers

Core Constructions

When windings surround the core, the transformer is **core form**; when windings are surrounded by the core, the transformer is **shell form**.



Core form



Shell form

Solid Core - Circuits like switch-mode power supplies that operate above mains frequencies and up to a few tens of kilohertz use powdered iron cores. For higher frequencies, cores made from non-conductive magnetic ceramic materials called ferrites are common.

Toroidal Core - Toroidal transformers are constructed around a ring-shaped core, made from a long strip of silicon steel or permalloy wound into a coil, powdered iron, or ferrite.

Air Core - Used in RF applications, air core transformers are constructed by placing the windings very close to each other. This design eliminates core losses.

Laminated Core - Transformers for use at power or audio frequencies typically have cores made of high permeability silicon steel. The effect of laminations is an enormous reduction of eddy currents.