# 15.2 Step-by-step transformer design procedure

The following quantities are specified, using the units noted:

| | | |
|---|---|---|
| Wire effective resistivity | $\rho$ | ($\Omega$-cm) |
| Total rms winding current, ref to pri | $I_{tot}$ | (A) |
| Desired turns ratios | $n_2/n_1$, $n_3/n_1$, etc. | |
| Applied pri volt-sec | $\lambda_1$ | (V-sec) |
| Allowed total power dissipation | $P_{tot}$ | (W) |
| Winding fill factor | $K_u$ | |
| Core loss exponent | $\beta$ | |
| Core loss coefficient | $K_{fe}$ | (W/cm$^3$T$^\beta$) |

Other quantities and their dimensions:

| | | |
|---|---|---|
| Core cross-sectional area | $A_c$ | (cm$^2$) |
| Core window area | $W_A$ | (cm$^2$) |
| Mean length per turn | $MLT$ | (cm) |
| Magnetic path length | $\ell_e$ | (cm) |
| Wire areas | $A_{w1}, \ldots$ | (cm$^2$) |
| Peak ac flux density | $\Delta B$ | (T) |



# Procedure

## 1. Determine core size

$$K_{gfe} \geq \frac{\rho \lambda_1^2 I_{tot}^2 K_{fe}^{(2/\beta)}}{4 K_u \left(P_{tot}\right)^{\left((\beta+2)/\beta\right)}} 10^8$$

Select a core from Appendix D that satisfies this inequality.

It may be possible to reduce the core size by choosing a core material that has lower loss, i.e., lower $K_{fe}$.

## 2. Evaluate peak ac flux density

$$\Delta B = \left[ 10^8 \; \frac{\rho \lambda_1^2 I_{tot}^2}{2K_u} \; \frac{(MLT)}{W_A A_c^3 \ell_m} \; \frac{1}{\beta K_{fe}} \right]^{\left(\frac{1}{\beta+2}\right)}$$

At this point, one should check whether the saturation flux density is exceeded. If the core operates with a flux dc bias $B_{dc}$, then $\Delta B + B_{dc}$ should be less than the saturation flux density $B_{sat}$.

If the core will saturate, then there are two choices:

- Specify $\Delta B$ using the $K_g$ method of Chapter 14, or
- Choose a core material having greater core loss, then repeat steps 1 and 2



## 3. and 4. Evaluate turns

Primary turns:

$$n_1 = \frac{\lambda_1}{2\Delta B A_c} \; 10^4$$

Choose secondary turns according to desired turns ratios:

$$n_2 = n_1 \left( \frac{n_2}{n_1} \right)$$

$$n_3 = n_1 \left( \frac{n_3}{n_1} \right)$$

$$\vdots$$

## 5. and 6. Choose wire sizes

Fraction of window area assigned to each winding:

$$\alpha_1 = \frac{n_1 I_1}{n_1 I_{tot}}$$

$$\alpha_2 = \frac{n_2 I_2}{n_1 I_{tot}}$$

$$\vdots$$

$$\alpha_k = \frac{n_k I_k}{n_1 I_{tot}}$$

Choose wire sizes according to:

$$A_{w1} \le \frac{\alpha_1 K_u W_A}{n_1}$$

$$A_{w2} \le \frac{\alpha_2 K_u W_A}{n_2}$$

$$\vdots$$



## Check: computed transformer model

Predicted magnetizing inductance, referred to primary:

$$L_M = \frac{\mu n_1^2 A_c}{\ell_m}$$

Peak magnetizing current:

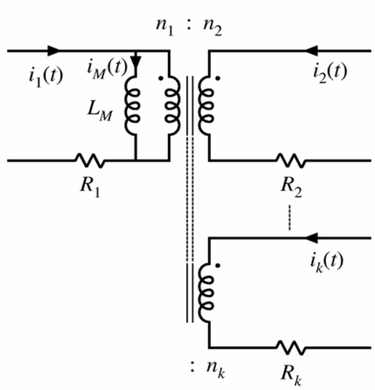
$$i_{M,\,pk} = \frac{\lambda_1}{2L_M}$$

Predicted winding resistances:

$$R_1 = \frac{\rho n_1 (MLT)}{A_{w1}}$$

$$R_2 = \frac{\rho n_2 (MLT)}{A_{w2}}$$

$$\vdots$$

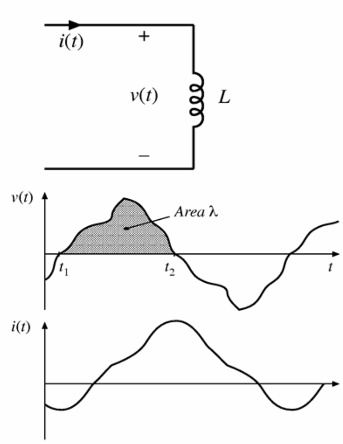


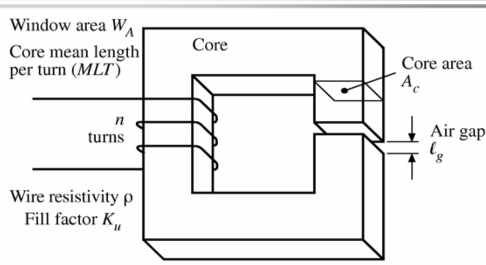
# Discussion: Transformer design

- Process is iterative because of round-off of physical number of turns and, to a lesser extent, other quantities
- Effect of proximity loss
  - Not included in design process yet
  - Requires additional iterations
- Can modify procedure as follows:
  - After a design has been calculated, determine number of layers in each winding and then compute proximity loss
  - Alter effective resistivity of wire to compensate: define
    $\rho_{eff} = \rho \cdot P_{cu}/P_{dc}$ where $P_{cu}$ is the total copper loss (including proximity effects) and $P_{dc}$ is the copper loss predicted by the dc resistance.
  - Apply transformer design procedure using this effective wire resistivity, and compute proximity loss in the resulting design. Further iterations may be necessary if the specifications are not met.



# 15.4 AC Inductor Design




Design a single-winding inductor, having an air gap, accounting for core loss

(note that the previous design procedure of this chapter did not employ an air gap, and inductance was not a specification)

# Outline of key equations

Obtain specified inductance:

$$L = \frac{\mu_0 A_c n^2}{\ell_g}$$

Relationship between applied volt-seconds and peak ac flux density:

$$\Delta B = \frac{\lambda}{2 n A_c}$$

Copper loss (using dc resistance):

$$P_{cu} = \frac{\rho n^2 (MLT)}{K_u W_A} I^2$$

Total loss is minimized when

$$\Delta B = \left[ \frac{\rho \lambda^2 I^2}{2 K_u} \frac{(MLT)}{W_A A_c^3 \ell_m} \frac{1}{\beta K_{fe}} \right]^{\left(\frac{1}{\beta + 2}\right)}$$

Must select core that satisfies

$$K_{gfe} \geq \frac{\rho \lambda^2 I^2 K_{fe}^{(2/\beta)}}{2 K_u \left(P_{tot}\right)^{\left((\beta + 2)/\beta\right)}}$$

*See* Section 15.4.2 for step-by-step design equations