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Winding Turn Lengths And Areas For Magnetic Components (Part 2): Square Windows

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In the design of magnetic components with round or square winding windows, winding lengths and areas are required. Winding resistance varies proportionally with winding length, and for a given number of turns, the wire size that fits the allotted winding area is calculated from the geometrically-derived available area.

Part 1 of this article[1] derived winding lengths and areas for round windows. The formulas presented here in part 2 apply to core shapes with rectangular windows. More specifically, this part presents the design formulas and their derivations for square (or nearly square) windows.

Winding Turn Length: Square Window

Square winding windows are commonly found in EE, EI, and EFD cores. The geometric features shown in Fig. 1 include the inside (a_i) and outside (a_o) distances of the winding from its center, the winding height Δa, and the radius of the corners of a turn r. Average layer center height is $\bar{a}$.

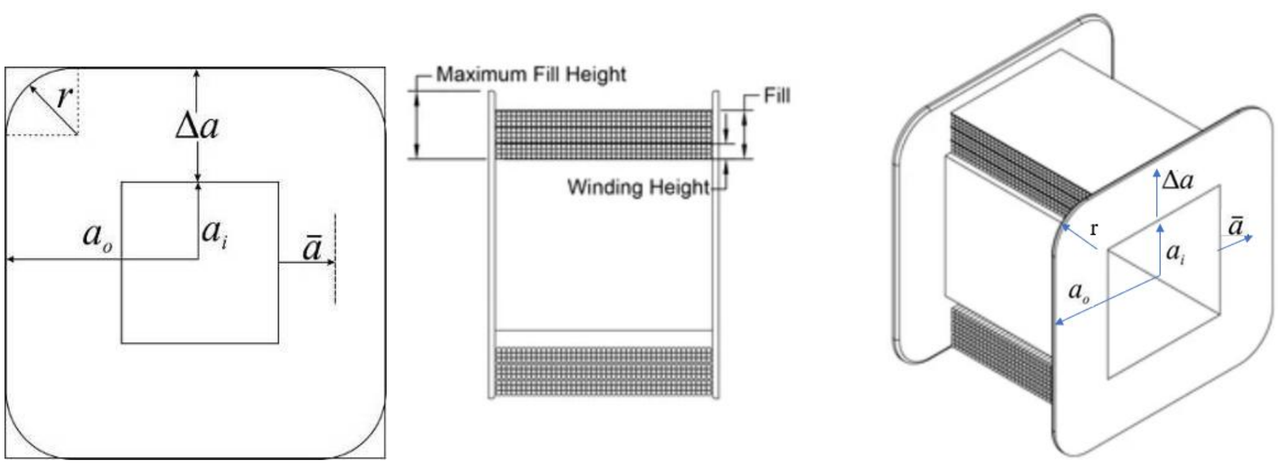

Fig. 1. Square winding window with rounded corners of radius r, inner dimension a_i and outer dimension a_o. A side view of winding area is shown on the left. Rotated views of the bobbin are shown in the middle and on the right—these two drawings are courtesy of EDCOR Electronics.[2]

For no corner rounding (r = 0) and distance a from the winding center, the turn length is

$$l_c = (2 \cdot a) \cdot 4 = 8 \cdot a$$

For M layers, then the radius of the first-layer corner is $r_1 = r_{cw}$. For layer m = 2, $r_2 = 3 \cdot r_{cw}$ for aligned packing, as shown in Fig. 2.

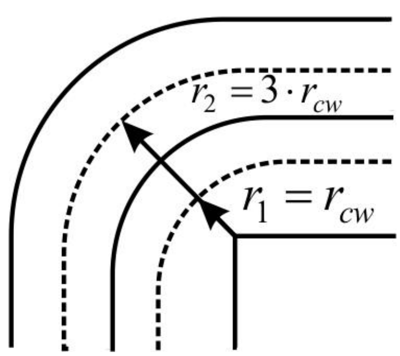

Fig. 2. Detail of the turn radii for layers 1 and 2 of the winding at the corners.

However, inner layers have packing averaged between square and hex configurations so that their separation is less than $2 \cdot r_{cw}$ and is $k_{pl} \cdot r_{cw}$ where $k_{pl} = 1 + \sqrt{3}/2 \approx 1.866$. Then for the *m*th layer,

$$r(m) = (k_{pl} \cdot r_{cw}) \cdot (m-1) + r_{cw} = [1 + k_{pl} \cdot (m-1)] \cdot r_{cw},\ m = 1,\ \ldots,\ M$$

The wire center height from the winding center for layer *m* is

$$a(m) = a_i + r(m) = a_i + [1 + k_{pl} \cdot (m-1)] \cdot r_{cw}$$

The winding height for *M* layers includes the outer-layer r_{cw};

$$\Delta a = a_o - a_i = (a(M) + r_{cw}) - a_i = [2 + k_{pl} \cdot (M-1)] \cdot r_{cw}$$

The number of layers can be expressed in turns, *N* and winding width w_w as

$$M = \frac{N \cdot (2 \cdot r_{cw})}{w_w}$$

Then the average height of the winding from its center is

$$\bar{a} = \frac{1}{M} \cdot \sum_{m=1}^{M} a(m) = \frac{1}{M} \cdot \left[\sum_{m=1}^{M} [a_i + (1 - k_{pl}) \cdot r_{cw}] + k_{pl} \cdot r_{cw} \cdot \sum_{m=1}^{M} m \right] \Rightarrow$$

$$\bar{a} = a_i + (1 - k_{pl}) \cdot r_{cw} + \tfrac{1}{2} \cdot k_{pl} \cdot r_{cw} \cdot (M+1)$$
$$= a_i + \tfrac{1}{2} \cdot (2 + k_{pl} \cdot (M-1)) \cdot r_{cw} = a_i + \frac{\Delta a}{2}$$

For turns with wire radius *r*, the corner arc length is $(\pi/2) \cdot r$. The turn length of layer *m* is the sum of the four sides, each of length $2 \cdot (a - r)$, and four corners:

$$l_c(m) = 8 \cdot (a(m) - r(m)) + 4 \cdot (\pi/2) \cdot r(m)$$
$$= 8 \cdot a_i + 2 \cdot \pi \cdot [1 + k_{pl} \cdot (m-1)] \cdot r_{cw}$$

Then the average length of a square turn with corner radius *r* is

$$\bar{l}_c = \frac{1}{M} \cdot \sum_{m=1}^{M} l_c(m) = \frac{1}{M} \cdot \sum_{m=1}^{M} (8 \cdot a_i + 2 \cdot \pi \cdot [1 + k_{pl} \cdot (m-1)] \cdot r_{cw}) \Rightarrow$$

$$\bar{l}_c = 8 \cdot a_i + 2 \cdot \pi \cdot [1 + k_{pl} \cdot (M-1)] \cdot r_{cw} = 8 \cdot a_i + 2 \cdot \pi \cdot (\Delta a - r_{cw})$$

The total winding length, including layer spiraling length w_w is

$$l_w = N \cdot \bar{l}_c + M \cdot w_w = N \cdot (\bar{l}_c + 2 \cdot r_{cw})$$

For the full winding window, set a_o to the window outer dimension.

Winding Area: Square Window

A similar exercise for square window cores and bobbins such as EE or EI cores has the winding window apportioned as shown in Fig. 3.

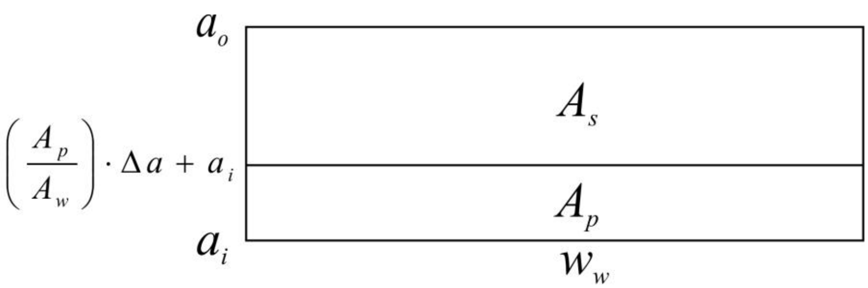

Fig. 3. Apportionment of primary and secondary winding areas for window of width w_w and height $a_o - a_i$.

The average turn lengths in area ratios for primary and secondary windings, based on previous turn-length derivations, are

$$\bar{l}_{cp} = 8 \cdot a_i + \pi \cdot \left\{ \left[\left(\frac{A_p}{A_w} \right) \cdot \Delta a + a_i \right] - a_i \right\} = 8 \cdot a_i + \pi \cdot \Delta a \cdot \left(\frac{A_p}{A_w} \right)$$

$$\bar{l}_{cs} = 8 \cdot \left[\left(\frac{A_p}{A_w} \right) \cdot \Delta a + a_i \right] + \pi \cdot \left\{ a_o - \left[\left(\frac{A_p}{A_w} \right) \cdot \Delta a + a_i \right] \right\}$$

$$= 8 \cdot a_i + \pi \cdot \Delta a \cdot \left[1 + \left(\frac{8}{\pi} - 1 \right) \cdot \left(\frac{A_p}{A_w} \right) \right]$$

Then the average turn length ratio is

$$\frac{\bar{l}_{cs}}{\bar{l}_{cp}} = \frac{1 + \left(\frac{\pi}{8} \right) \cdot \left(\frac{\Delta a}{a_i} \right) + \left(1 - \frac{\pi}{8} \right) \cdot \left(\frac{\Delta a}{a_i} \right) \cdot \left(\frac{A_p}{A_w} \right)}{1 + \left(\frac{\pi}{8} \right) \cdot \left(\frac{\Delta a}{a_i} \right) \cdot \left(\frac{A_p}{A_w} \right)}$$

The average window depths for the windings are

$$\bar{a}_p = a_i + \tfrac{1}{2} \cdot \left(\frac{A_p}{A_w} \right) \cdot \Delta a$$

$$\bar{a}_s = \tfrac{1}{2} \cdot \left[\left(\frac{A_p}{A_w} \right) \cdot \Delta a + a_i + a_o \right]$$

Following previous derivation, the fraction of primary window area is

$$\frac{A_p}{A_w} = \frac{1}{1 + \frac{A_s}{A_p}} = \frac{1}{1 + \frac{1}{n} \cdot \frac{\tilde{i}_s}{\tilde{i}_p} \cdot \sqrt{\frac{\bar{l}_{cs}}{\bar{l}_{cp}} \cdot \frac{\bar{a}_p}{\bar{a}_s} \cdot \frac{k_{pp}}{k_{ps}}}} \approx \frac{1}{2}$$

Then the optimal winding areas for square windows is the same as for round windows:

$$A_p = A_s = A_w/2$$

These design formulas for winding lengths and areas become part of a larger magnetics component design procedure. The formulas are valid for small wire relative to winding dimensions as shown in Fig. 3 for which turn diameter is much less than either w_w or window height. Otherwise, turns fitting considerations apply as covered in a previous magnetics article.[3]

References

1. "Winding Turn Lengths And Areas For Magnetic Components (Part 1): Round Windows" by Dennis Feucht, How2Power Today, January 2026.
2. "Designing a Transformer, Part 3: Physical Design Calculations," EDCOR Electronics blog.
3. "Optimizing Winding Design For Low-Resistance Windings—Selecting Wire Or Bundle Size To Fill The Core Window" by Dennis Feucht, How2Power Today, February 2024.

About The Author

Dennis Feucht has been involved in power electronics for 40 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been working on projects in theoretical magnetics and power converter research.

For more on magnetics design, see these How2Power Design Guide search results.