# User-friendly Data for Magnetic Core Loss Calculations

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## Abstract:

*Graphs of magnetic core loss data are usually for sine-wave excitation and presented in terms of maximum flux density $\widehat{B}$ and frequency f. These graphs are of questionable value for pulse-width-modulated (pwm) power converter design and decidedly not user-friendly. Graphs of core loss data for square-wave excitation, presented in terms of applied voltage and time are much more relevant to pwm power converter design and are much easier to use.*

## Background:

Magnetic core loss graphs from manufacturers are marginally useful for pwm power converter design. (1) They usually present loss in terms of maximum flux density $\widehat{B}$, an unfamiliar parameter of little use to the power converter designer. (2) The magnetic units used for core loss graphs are confusing and inconsistent. The likelihood of making errors is significant. (3) The graphs are for sine-wave excitation. Most pwm converters operate with square-waves having a variable duty-cycle. (4) The graphs are notoriously inaccurate. It is not unusual to see ruler-straight lines on core loss curves, with gross inaccuracies at the extremes.

## Using volt-second graphs

### The data:

Figure 1 shows representative core loss curves for square-wave excitation, presented as a family of constant voltage curves vs. pulse-width *t*.

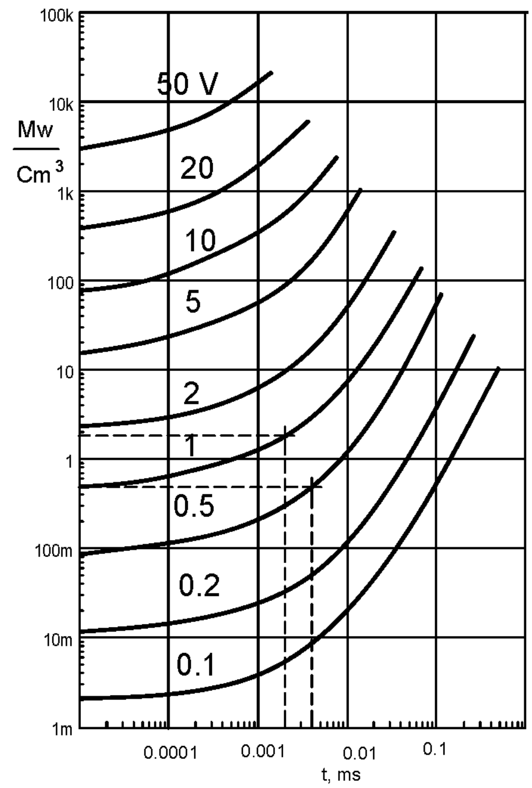


**Figure 1:** Representative core loss curves for constant voltage square-wave excitation vs. pulse-width.

For a material, the voltage is normalized and has units of volts per $cm^2$ turn and the loss is in watts per $cm^3$. Core loss graphs for specific cores include the geometric parameters, so the units are volts/turn and watts.

## Calculations

**See figure 2 to define pulse-width and duty-cycle:** In all cases, the pulses are repetitive steady-state pulses, as would be generated in a pwm converter at stead-state conditions.

**For a square-wave excitation**, *t* is the pulse-width and *T* is the period. The duty-cycle *D* is 1.0. To calculate the core losses using figure 1 for a 1 volt square-wave with a pulse-width of 2 us, follow the dashed line up from 2 us to intercept the 1 volt curve, then horizontally to intercept the vertical axis. The result is about 1.8 mw/cm$^3$.

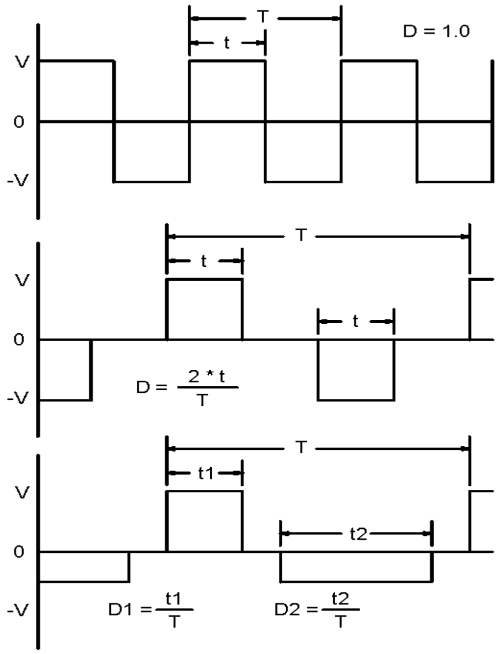


**Figure 2:** Times and duty-cycles defined.

**For a symmetrical pulsed excitation,** *t* is the pulse-width and *T* is the period. The duty-cycle *D* is 2 * *t / T*. To calculate the core loss for a 1 volt pwm wave-form having a 1 volt excitation and a 2 us pulse-width and a duty-cycle of 0.5, follow the dashed line up from 2 us to intercept the 1 volt curve, then horizontally to intercept the vertical axis. The result is multiplied by the duty-cycle 0.5 to give about 0.9 mw/cm$^3$.

**For an asymmetrical pulsed excitation,** the volt-seconds must be equal for the positive and negative pulses. T is the period, *t1* is the positive pulse-width, *t2* is the negative pulse-width. Two duty-cycles are defined, *D1 = t1 / T* and *D2 = t2 / T*.

To calculate the core loss for an asymmetrical pwm having a period of 8 us, and having a 2 us positive pulse of 1 volt and a 4 us negative pulse of 0.5 volt, first follow the dashed line up from 2 us to intercept the 1 volt curve, then horizontally to intercept the vertical axis. The result is multiplied by the duty-cycle of 0.25 to give about 0.45 mw/cm$^3$.

Next, follow the dashed line up from 4 us to intercept the 0.5 volt curve, then horizontally to intercept the vertical axis. The result is multiplied by the duty-cycle of 0.5 to give about 0.24 mw/cm$^3$. Add the partial results. The core loss is about 0.69 mw/cm$^3$.

Thus a method of calculating core loss is presented that does not require calculating magnetic parameters. This data and the calculations are much more relevant to power converter design, and much more user-friendly.

## Saturation

Following the constant voltage curves from left to right, the volt-seconds of each point is the product of the voltage and the pulse-width. The curve ends at the volts-seconds where the core saturates (or some lower limit, set by the manufacturer).

Accordingly, as long as the voltage and pulse-widths of interest are on the curve, the core will not saturate (if there is no flux walking.)

Knowing that the right-hand limit of the curve represents "saturation", the percentage of saturation for any shorter pulse-width is given by the ratio of the pulse-width of interest to the pulse-width at the right end of the curve, times 100%.

## Loss data for cores and wound components

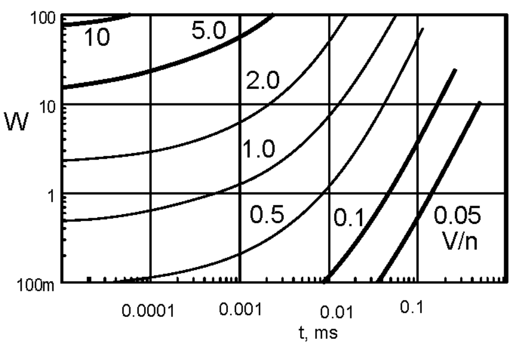


**Figure 3.** For a specific core, the geometric parameters are included, so the result is read directly as watts W.

**Losses for cores:** A manufacturer of magnetic cores can present data for any specific core with all of the geometric parameters included, so the user need not concern himself with effective area, effective volume and the like. Knowing the volts/turn and the pulse-widths of interest, the losses in the core can be read directly from the graph, as seen in Figure 3.

**Losses for wound components:** A similar graphical presentation includes the turns, allowing a designer to determine the core losses directly using only the voltage and pulse-widths.

[Paragraphs and figures deleted]

## *Low duty-cycle data*

In figure 8, curves of constant average voltage equal to 0.5 V were plotted for several frequencies. For example, using the technique for low duty-cycles presented above, start with the 0.5 V line and 0.01 ms, point A. That is the power for a square wave with 0.01 ms pulse width. At 0.001 ms, to have the same <u>average voltage</u>, the voltage during the pulse is 5.0 V, point B, reduced by the duty-cycle 0.1, point C. The line A-C is approximately the line showing the loss for constant average voltage. This may be the most useful curve of all for a power converter designer.

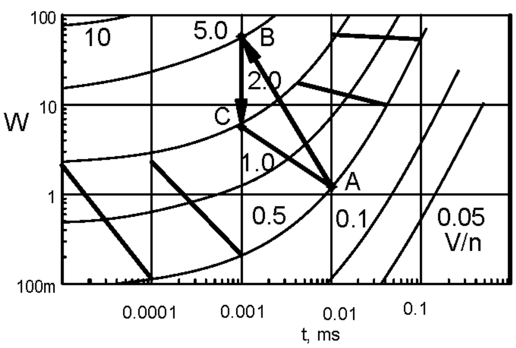


**Figure 8.** Curves of constant average voltage can be plotted. Note the extreme change in slope for short pulse widths (high frequency).

The same technique is repeated to estimate the losses at constant average voltage for other starting pulse-widths, resulting in the family of curves shown in figure 8.

Note that at short pulse-widths (high frequency), the losses rise significantly at low duty-cycle. At longer pulse-widths, (low frequency), the duty-cycle does not much affect losses. This is the classic loss characteristic taught for magnetic design.

## *Qualitative data*

These curves are derived from Steinmetz equations applied far beyond their limits of reasonable accuracy, using many complex manipulations, each an opportunity for error. Accordingly, the graphs are qualitative at best.

However, the graphs represent a suggested form to use for plotting "real" data, from laboratory test and measurement. Real data from real tests will always trump manipulated data and approximations.

This data is user friendly and much more meaningful for power converter design.

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