QuickApp Toroid Design
Abstract

• Ferrite and iron powder toroids are often used to create custom inductors and transformers in radio frequency (RF) applications.
• The finger-friendly eightolives QuickApp Toroid tool helps relate the key parameters in toroid design.
Toroids

- Toroids are made of various magnetic materials with different properties. Major categories are:
  - Powdered iron cores
  - Ferrites
- The inductance varies as a function of the materials magnetic constant (μ), number of turns of wire, toroid core physical dimensions
- The performance is effective over a frequency range
Limiting Factors

- The maximum number of turns is a function of wire size and toroid inner diameter
- Wire size and turns add resistance which dissipates power and lowers the inductor's Q
- Saturation flux limits relate to overheating
- More than a single layer of windings can cause additional unwanted resonances
Frequency Ranges For Resonance

Material: Powdered iron, Ferrite, Phenolic

Copyright © 2011 William Kaupinis All Rights Reserved
Maximum Single Layer Turns

\[ R = \text{core inner radius} \]

\[ r = \text{wire outer radius} \]

\[ \Phi = \arcsin(r / (R-r)) \]

\[ N_{\text{max}} < \pi / \Phi \]

When \( r < R \)
Temperature Rise

- Temperature rise is caused by loss in the winding and loss in the core
- Temp Rise = \left(\frac{P_{\text{diss}}(mW)}{\text{SurfaceArea}}\right)^{.833}
  - Still Air estimate
- We recommend design for a 25 degree C rise max
- Wire loss is determined by current and wire size
- Core losses are more difficult to estimate
  - Insufficient data on many materials
  - Losses vary due to several parameters
Estimating Flux Density

- Maximum flux density
- Faraday's Law
  - \( V = 4.44 \, F \, N \, Ae \, B_{\text{peak}} = \text{Math.sqrt}(2) \times \pi \, F \, N \, Ae \, B_p \)
- In the Toroid Tool you specify coil current \( \text{Irms} \)
  - \( I_{\text{peak}} = \text{Math.sqrt}(2) \times \text{Irms} \)
  - \( E = L \, \frac{di}{dt} = L \times \text{Math.sqrt}(2) \times \text{Irms} \times 2 \times \pi \times F \)
- Equating the two:
  - \( B_{\text{peak}} = 2 \times \text{Irms} \times L / (N \times Ae) \)
Inductance

- Inductance is calculated using the manufacturer provided factors

- In general
  - \[ L = \mu \mu_0 \frac{h}{2\pi} \ln\left(\frac{b}{a}\right) \times N^2 \]

  where
  - \( \mu \) is permeability of the core material
  - \( \mu_0 \) is \( 4 \times \pi \times 10^{-7} \)
  - \( H \) is core height
  - \( B \) outside radius
  - \( A \) inside radius
  - \( N \) number of turns of wire
Start at:
http://www.eightolives.com/docs/Mobile/navigate/navigate.htm

- or start from the eightolives.com Home Page and click “QuickApps”
- The main menu lets you select the QuickApps menu or other eightolives resources

Hint: Bookmark the link to this menu.
Then Pick the Toroid Tool
Enter numbers then press the F, Iac, Idc, L or TURNS buttons.

RND rounds the TURNS entry.
Scroll down for the Core Size, Material and Wire Size selectors.

The Design Report is in the bottom text area.
Using the Toroid Tool

- Select material, core and wire size from the drop down selectors
- Enter numbers using the buttons and then press the L or TURNS button
  - The other parameter is calculated
  - Use the RND key to round the number of turns
- Entering values for AC RMS current (IAC) or DC current (IDC) will estimate power dissipation
- A Design Report is presented in the text area at the bottom of the tool display.
Generated Design Report

Inductor T-37-2 - Specifies the part designation

Inductance = 1.024 uH - Specifies the inductance

Number of Turns = 16 - The number of turns of wire needed

Max single layer turns = 23 - The max number of single layer turns possible for the core and wire size

Wire size = 24 - The wire size used assumes triple enamel insulation

Wire resistance = 0.03 ohms - An estimate of the wire resistance

Wire length = 17.40 in - An estimate of the length of wire needed.

Wire capacity = 0.57 A cont - The max current rating for the wire.

Iac = 0.01 A rms - Your estimate of inductor rms AC current.

Idc = 0 A - Your estimate of inductor DC current.

Permeability u = 10 - The permeability of the selected core material

Design frequency = 28 MHz - The intended design operating frequency.

Frequency range = 2 - 30 MHz - The manufacturer's recommended range for resonance applications.

Impedance = 180.15 ohms - The estimated impedance of the inductor at the design frequency.

Estimated Q* = 4839.32 - The estimated unloaded Q of the inductor.

Estimated flux density* = 1.80 gauss - The estimated ideal flux density for the given conditions.

Est. Core Loss* = 7.71 mW/cm**3 - The estimate core loss parameter.

Wire Loss* = 0.00 Watts - The estimated power loss due to the wire used.

Core Loss* = 0.00 Watts - The estimated ideal loss in the core.

Calculated Voltage = 2.52 Volts - The estimated equivalent max voltage across the inductor given the current specs.

Power dissipation* = 0.00 Watts - Estimated total power dissipation of the inductor.

Temp rise still air* = 1.80 C - Estimated still air temperature rise after a long operating period.

Maximum flux density* = 29.85 gauss - An estimate of the flux density for the specified conditions.

* indicates a rough approximation
Reality Check

- Some of the estimates made are based on ideal circumstances and may not reflect reality.
- Core saturation limiting effects are not considered in the computations.
  - This makes core power losses and temperature rise unrealistic at higher values.
  - It means that additional investigation is required if they are too high.
- Max flux estimates are derated for design frequency.
Reality Check

• Things to verify in your design:
  • The required number of turns < max possible turns
  • Iac + Idc < Wire capacity current
  • Design frequency is compatible with mfg recommendation
  • Estimated flux density is less than the estimated Max flux density and always less than ~1000
  • The Calculated Voltage is realistic for your system
  • The still air temperature rise is less than 25 C or you may need heat sinking or moving air
Reality Check

- Modify Wire Size, Core Size and Material until you get an acceptable design solution
- Variations in manufactured core material and construction may yield inductance variation of +/- 10 to +/- 20%
Hints

- Bookmark the menu page so you can easily access the tools.
- Calculations automatically occur on data entry solving for a likely parameter. To specify the parameter to solve, press the parameter button then press the SLV button.
For more information

- http://www.micrometals.com
- https://www.amidoncorp.com/
- http://www.palomar-engineers.com/
- Check the QuickApps Overview for more info on the other apps from the tutorials page at: http://www.eightolives.com/tutorials.htm
- Review bug reports and status from the QuickApps home page at: http://www.eightolives.com/docs/Mobile/index.htm