Coupled Inductor Confusion

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Outline

- Schematic confusion
- Common mode choke
- Dual mode chokes
- Multi-winding output inductor
- Classic coupled inductor
- Flyback transformer
- Inductors for multi-output buck
- Transductors – Magnetic Amplifiers
- Symbols by standards
Schematic confusion

Transformer

Common mode choke

Coupled inductor

Flyback transformer
What is an inductor, choke, reactor?

- What is the difference?
- An inductor is a two terminal magnetic device that has the property of inductance (L)
- They come in many shapes and sizes
- Basically a coil of wire, usually with a core
- When current flows through the coil, a voltage potential develops across the terminals that opposes the change in current and energy is stored in the magnetic field
- Resists changes in current – mechanically it acts like a flywheel
- Unlike a capacitor, the inductor cannot hold its energy
- ‘Choke’ often used for filter inductors with dc bias
- ‘Reactor’ often used for ac only inductors
Definitions

- **Inductor:**
  - An magnetic device that impedes the change in the flow of electric current by storing and releasing energy from its magnetic field.

- **Coupled Inductor:**
  - A coupled inductor is an inductor with two or more windings on the same core which takes advantage of magnetic coupling to influence the behavior of each winding on the other.

- **Transformer:**
  - A magnetic device that transfers energy instantaneously through its magnetic field. Typically changes the voltage or current and can provide galvanic isolation.
Common Mode Choke

- a.k.a current compensated chokes
- Windings are in the same direction through the core
- Flux from differential currents cancel in core
- Allows use of high permeability cores which are sensitive to dc bias
- Reduces number of turns which reduce winding self capacitance which limits high frequency response
- The common mode currents are in parallel
- The filter is smaller than using two cores
- Tight coupling desired
CMC – Ferrite Bead

- A wire through a toroid – ferrite bead or snap on
- The cores are usually lossy converting high frequency noise to heat
CMC – Low voltage

- Add more turns for increased inductance
- Add a second, or more windings for common mode
CMC – High Voltage

- Separate the windings for high voltage
Less distortion for signals

Input waveform  |  Output waveform
--- | ---

Input waveform  |  Output waveform

Input waveform  |  Output waveform

+  |  -

Input waveform  |  Output waveform

+  |  -
Dual mode inductors

- Two inductors one
- Common mode and differential mode combined
- Adding leakage inductance to create differential mode filtering
Classic coupled inductors

- Ćuk definition:
  
  “A coupled inductor is one where if the coupling is removed, the converter must still operate.”

- Coupled inductor chosen to reduce component count and lower inductance requirement
- Coupling (leakage) is important
- Coupling reduces the inductance required because fluxes add
- Coupling can steer the ripple current to the input or output
- Tight coupling is not desired
Classic Ćuk

- Similar to SEPIC, Zeta
- Coupling reduces the inductance required
- Coupling can steer the ripple current one way of the other
- Tight coupling is not desired
- SEPIC and Zeta are similar
Classic coupled inductor - Ćuk

- Tight coupling introduces circulating currents
- Zero ripple current very difficult to get in practice

\[ L = \frac{E dt}{di} \]
SEPIC

- Non inverting
- Ground referenced
- Low ripple
- Can use individual or coupled inductors
Multi-winding inductors

- Excellent AC cross regulation because all outputs are dynamically coupled
- Large overshoot/undershoot is reduced because all outputs absorb or provide energy as necessary to support any output load change
- Although each output still requires a minimum load, the consequence of violating it are less severe
- Simplified current limiting. A single primary side current limit will prevent inductor saturation regardless of which output is overloaded
- Loop gain irregularities are eliminated because the coupled inductor is dynamically in common with all outputs combining them into a single circuit resonant frequency
- Single filter inductor is lower in cost and has a smaller volume
- Output filter capacitor size and cost can be reduced by steering most of the ripple current to the highest voltage output

Reference: Coupled Filter Inductors in Multi-Output Buck Regulators, Lloyd Dixon, TI, slup082a
Steer ripple with leakage

\[ L_{LKG} = \frac{\mu_0 \mu_r N^2 (MLT \cdot S)}{W_W} \]
Flyback transformers

- By definition, as an energy storage device it’s an inductor.
- The circuit operates this device as two separate inductors that use the same core to link them together.
- Because they are linked by the mutual flux, the voltages and currents have transformer like property of turns ratio.
- Because the input and output use different windings it has the transformer property of galvanic isolation.
- It's not a transductor because that term is already used for a different device.
Isolated Flyback

- Transformer-choke
- Transformer isolated version of a buck-boost
- Each phase has its own inductor but share the same core
- One coil builds the magnetic field
- The other harvests it
- Voltages exist on both coils giving it transformer like ratios
Isolated Flyback

- Transformer isolated version of a buck-boost
- Both step up and step down
- Multiple outputs
- Optimizes duty cycle for large voltage differences
- Wide input range
Isolated Flyback

- Transformer isolated version of a buck-boost
- Both step up and step down
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- Optimizes duty cycle for large voltage differences
- Wide input range
Multi-output buck

- Clearly this multi winding inductor is operating like a flyback transformer
- PFC – Power factor correction chokes with auxiliary windings fall into this category
Transductors – Magnetic Amplifiers

- Multi winding inductor that uses a dc control winding to influence the impedance in the ac load winding

Magnetic Amplifiers: Theory and Application, Sidney Platt, 1958, Prenice-Hall
Glossary

- Choke → inductor intended to carry large DC currents
- Common mode choke → coupled inductor intended to limit common mode currents
- Coupled Inductor → a multiple winding inductor with interaction
- Current compensating choke → same as common mode choke
- Differential choke → inductor that can handle dc bias used in EMI suppression
- Flyback transformer – a type of coupled inductor taking advantage of transformer like properties
- Inductor → generic term for a device that stores energy or limits current changes
- Reactor → inductor for ac circuits to limit current
- Transductor → a variable coupled inductor for ac circuits that uses a dc control winding
- Transformer choke → an old, but true reference to a flyback transformer
- Transformer → transfers and transforms power instantaneously, does not store energy
Symbols – IEC 60617-4 Inductors

- 04-03-01 Inductor, Coil, Winding, Choke
- 04-03-03 Inductor with magnetic core
- 04-03-04 Inductor with gap in magnetic core
- 04-03-06 Inductor with fixed tap
Symbols - IEC 60617-6 Transformers

- 06-09-01 Transformer with two windings
- 06-09-02 Transformer with instantaneous voltage polarity indicators
- 06-10-02 Transformer with screen
- 06-10-04 Transformer with center tap
Summary

- There is probably no way to untangle this mess of what is called a ‘coupled inductor’
- But now you are smart enough to know the difference is based more on circuit topology than some idea about two windings on a core
- Coupled inductors are not transformers and they are not interchangeable.
- Coupled inductors exploit a benefit of several windings being on the same core
- Schematic symbols are all about context

- Learn to use the unique benefit of coupled inductors in your application
Thank you