Flat Transformer Technology Corp.

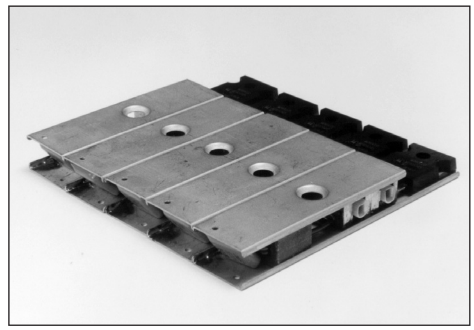
FTI-12x2A-1A
FTI-12x2A-1B
FTI-12x2A-1B-R
FTT KIT #1
FTT KIT #2
FTT KIT #3
FTT KIT #4
FTT KIT #5

APPLICATION NOTE AN01

Flat Transformer Technology's
TRANSFORMER-INDUCTOR MODULE
For Half Bridge, Full Bridge and Push Pull Circuits

By: James Lau, K. Kit Sum

Applicable Models: FTI-12x2A-1A, FTI-12x2A-1B, FTI-12x2A-1B-R, FTT KIT #1 to FTT KIT #5



When designing power supplies operating at 250 kHz, and above, the transformers and inductors are usually one of the biggest stumbling block. While there are many 'cookbook designs' on transformers and inductors, optimizing them requires complex calculations, and measurements with expensive equipment. In many cases, specific data on the core materials are not available from the manufacturers. Important design parameter such as leakage inductance is difficult to calculate and in addition, many designs require a very low profile. Thermal management is another important issue. Non uniform heat dissipation in transformers produces hot spots, and causes transformers to overheat.

Conventional transformers are designed with multiple windings on a single core. These windings cause higher leakage inductance, more noises and higher losses. Flat Transformer uses an innovative approach. Instead of using multiple windings on a single core, Flat Transformer uses a single winding on multiple cores, resulting in a modular structure with many inherent advantages.

The secondary winding in a Flat Transformer consists of a pair of copper plates that are bonded to the inside surface of square ferrite core. This winding follows a 180 degrees helical path. When the primary windings are sleeved through the core, the coupling between the primary and secondary windings is improved tremendously. This feature coupled with the absence of multiple windings, results in a very low leakage inductance, typically, around 4 nH per turn squared.

Flat Transformer's modular construction also has a low profile, high density, and vastly improved thermal characteristics, a combination not found in a conventional transformer design. In addition, a matching inductor is packaged into the module, resulting in a tightly integrated transformer-inductor module (FTI- series). Each module comes with easy to use mounting holes that can be fastened down to any flat surfaces with superior resistance to vibration.

The FTI series module make designing the entire output stage of the power supplies a very simple process. This application notes provide a step by step approach in designing the entire output stage consisting of the transformer, inductor, rectifiers, and output capacitors.

The FTI series of transformer inductor modules are optimized for a low output voltage, and a high output current. These modules have the lowest leakage inductance, and a minimal inter-winding capacitance. Low leakage inductance is important in high output current application. Each FTI module has a leakage inductance of 4nH per turns squared, which is about 2000 times smaller than any other types of comparable transformers. The modules are connected in parallel with a copper strap over the modules. Please see Figure 14.

Low leakage inductance and low inter-winding capacitance is possible because the number of passes over the cores, N, (usually referred as "number of turns") is low with Flat Transformers. The number of turns, N, is not to be confused with turns ratio, n.

Leakage inductance is given by:

$$L_{leakage} = \frac{0.4\pi\, N^2 A_e\, \mu}{L_e} \quad . \; . \; . \; . \quad (1)$$

Where,

N = *No. of turns,*
A_e = *Cross sectional core area* (cm^2)
μ = *Permeability of core in air*
L_e = *Magnetic path length (cm)*

As shown in equation 1, the number of passes through the core, N, is an exponential term. The leakage inductance is reduced in proportion to the number of module used. If two modules are connected, the number of turns is reduced by half. For example, if two modules are used, the leakage inductance is reduced to 1/2. and if five modules are used, the leakage is reduced to 1/5, etc.

Conventional Transformer

- Uses single core
- Large number of primary windings
- Substantial Leakage Inductance
- Poor high frequency response
- Bulky and difficult to package

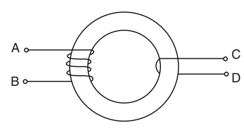


Fig. 1. Conventional Transformer

Flat Transformer

- Uses multiple cores
- Uses small number of primary windings
- Very low leakage inductance
- Excellent high frequency characteristics
- Low profile

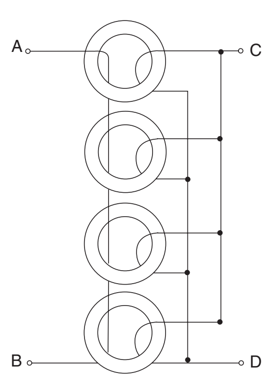


Fig. 2. Flat Transformer

FTI-12x2A-1A and FTI-12x2A-1B

These integrated FTI modules (Fig. 3 and Fig. 4) are designed for output voltages from zero to 15 volts at a maximum of 40 amps per module. The main difference between the two modules is the top and bottom plates. FTI-12x1A-1A does not have an extension on the bottom plate for the rectifier connection. In this case, the rectifier is mounted directly onto the heat sink. The FTI-12x1A-1B has a newer and better design of the top and bottom plates with an extension for rectifier connection. We recommend that all new power supply designs use the FTI-12x2A-1B configuration.

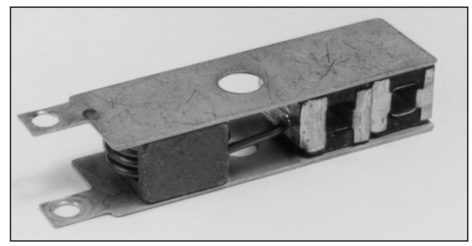


Fig. 3. FTI-12x2A-1A: 15V, 40 A,
"A" Version, no extension for rectifier.

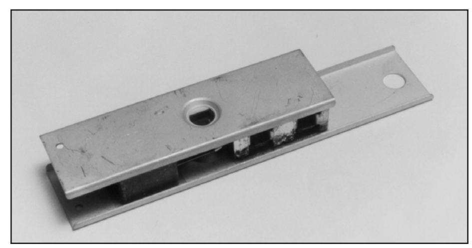


Fig. 4. FTI-12x2A-1B: 15V, 40 A,
"B" Version, with extension for rectifier.

FTI modules are ideally suited for half bridge, full bridge, and push pull topologies. This application note will illustrate a few design examples. The transformer section consists of two square shaped, low loss, high frequency and fully optimized proprietary ferrite cores with built-in secondary winding. The secondary winding, passes through each core, comprised of a pair of copper strip that follow a 180 degrees helical path so that the opposite ends of each core are ends of the same winding. In this way, when the two cores are soldered together, the secondary windings become continuous through the two cores. The secondary windings are bonded onto the inside surface of the ferrite core. Heat dissipated by the secondary windings can be conducted to the outside through the thin wall of the square ferrite core. This allows the transformer to operate with very low temperature rise.

Primary winding is not part of the module design. The designer needs to determine the number of primary winding required. Please see design examples in this application note.

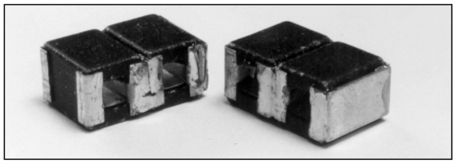


Fig. 5. Transformer Section: Two square ferrite cores with secondary windings pre-connected

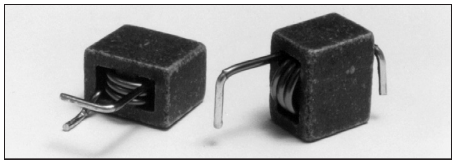


Fig. 6. Inductor Section: 3.5 turns on specially blended iron powder cores

The built-in inductor in FTI-12x2A-1A or 1B consists of a specially blended iron powder core. This built-in inductor is also available in MPP and Sendust material for high end applications. It has 3.5 turns of AWG #16 wire. Under normal circumstances, #16 wire for an inductor application handles 10 amps of current. The top and bottom copper plates are bonded to the inductor in the FTI module and these plates have large surface area for good heat dissipation. The copper plates which also doubles as the output terminals act as a good heat extractor, thereby allowing the #16 wire to handle up to 40 amps of current through the inductor.

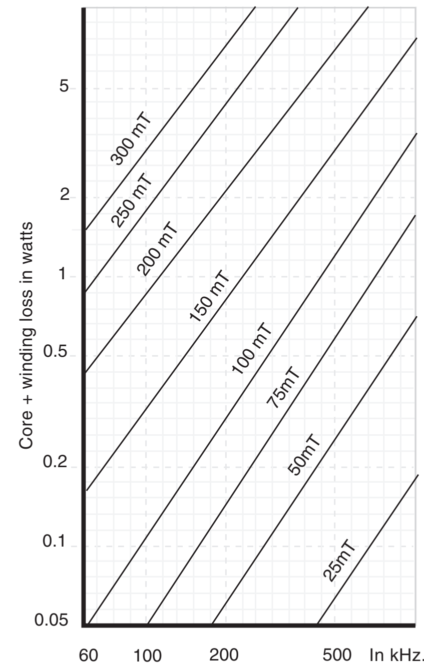
Table 1: Transformer Section	
Built-in secondary winding	1+1 center tap
Primary windings	Not connected
A_L (Magnetization Inductance)	6.8 µH / t^2
A_e (Eff. Cross section area)	0.68 cm^2
L_e (Magnetic length)	2.8 cm
V_c (Core volume)	2.0 cm^3
$L_{leakage}$ (leakage inductance)	4 nH / t^2

Table 2: Inductor Section- Iron Powder		
No. of windings	3.5 turns	(18 cm length)
Wire size (AWG # 16)	13.1 cm^2	(2581 cil mils)
Wire DC resistance	0.132 mΩ / cm	
Wire length	18 cm	(2.37 mΩ)
A_L (Magnetization Inductance)	180 nH / t^2	
A_e (Eff. Cross section area)	0.6 cm^2	
L_e (Magnetic length)	2.64 cm	
V_e (Core volumn)	1.53 cm^3	
DC Bias Characteristics		
Inductance at 0 amps (500 kHz)	2.2 µH	
Inductance at 10 amps	1.8 µH	
Inductance at 20 amps	1.4 µH	
Inductance at 30 amps	1.2 µH	

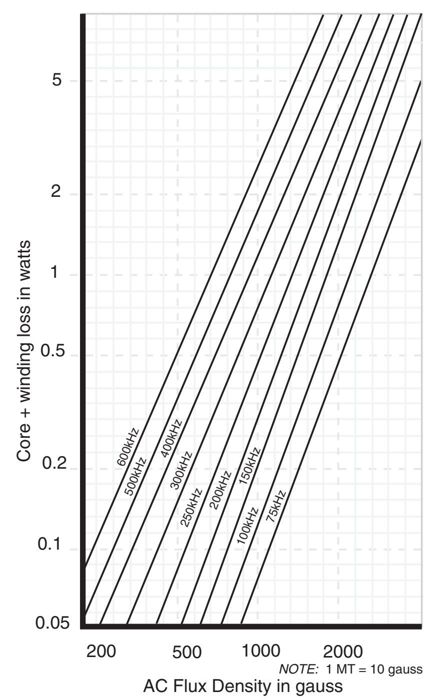
Different inductance values, wire sizes and materials (MPP or Sendust) is available. Please call.

Transformer Losses

The FTI-12x2A-1A or 1B module is designed for an output voltage of 0 to 15 volts. The output voltage is limited due to the single center tap turns in the secondary windings. At 5 Vdc output, and 250 kHz of operation, the transformer core is at 80 mT (800 gauss). Please refer to Graph 1 and Graph 2. At the maximum output of 15 volts, the core is operating at 240 mT, which is about 50% of the core's saturation. The saturation flux density of the transformer is about 450 mT.



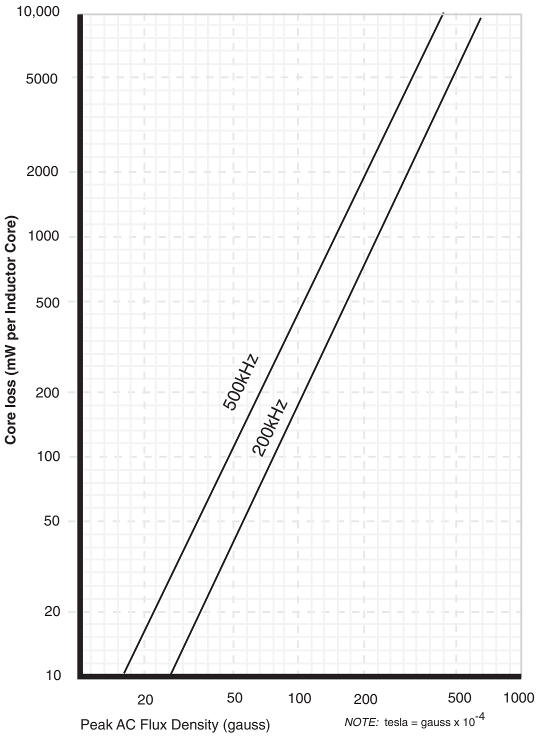
Graph 1. Core Loss Vs Frequency in kHz



Graph 2. Core Loss Vs Flux Density in gauss

Inductor Core loss

The inductor used in FTI-12X2A-1A or - 1B is made of iron powder material.
The core loss is shown in Graph 3.



Graph 3. Inductor Core loss Vs Peak AC Flux density

Accessories for the FTI Modules

Standard industry parts are used in the manufacture of the FTI series module. For small scale applications such as in engineering prototyping, all accessories required can be purchased from Flat Transformer Technology Corporation. These includes:

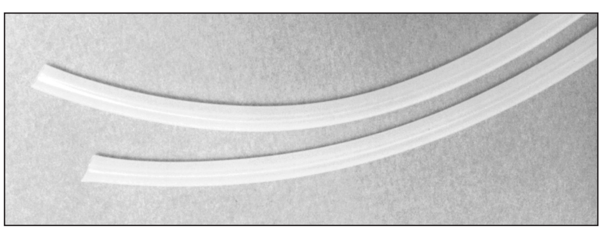


Fig. 7. Thin walled Teflon sleeve for isolating primary and secondary windings. (A dielectric break down of over 40,000 volts is possible with teflon sleeve insulation.)

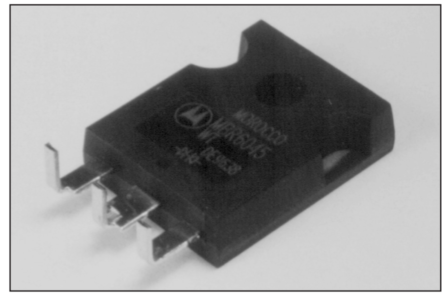


Fig. 8. Rectifiers with correctly sized packaging

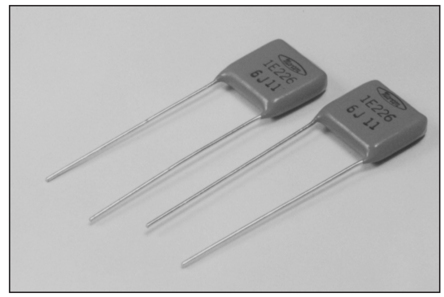


Fig. 9. Same profile and matching ceramic output capacitors

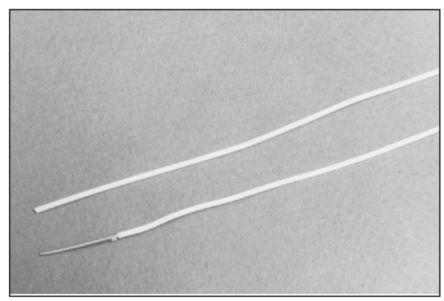


Fig. 10. Various sizes of Teflon coated wires used as primary windings

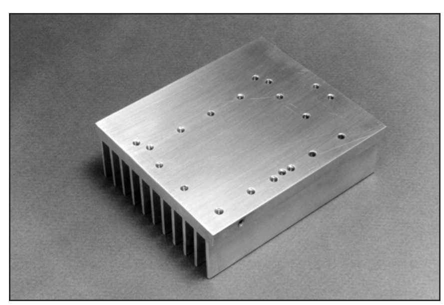
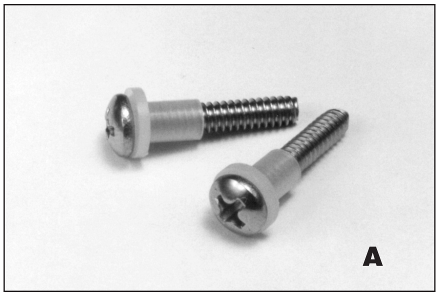


Fig. 11. Heat sinks with holes predrilled for connecting the modules



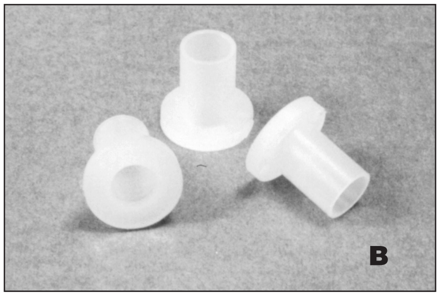
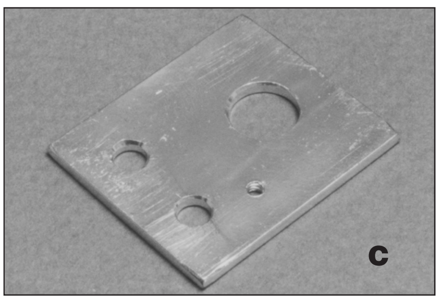


Fig. 12. A, B, — Hardware for connecting the modules to heat sinks



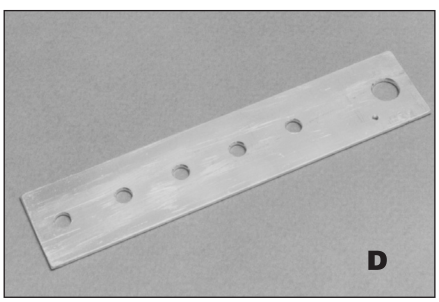


Fig. 13. C, D, — Power and Ground copper straps

Connection points for rectifiers, and output capacitors are also built into the module for easy connection to these devices. FTI-12x2A-1B is also available with the rectifier (MBR6045PT) pre-connected. The part number is: FTI-12x2A-1B-R. Matching ceramic output capacitors are also available through Flat Transformer. Please call technical support for more details.

FTT KIT # 1

Figure 14 shows a picture of transformer-inductor FTT KIT #1. It consists of 3 FTI-12x2A-1A or FTI-12x2A-1B modules connected on a piece of heat sink. The heat sink is acting as the positive terminal. The negative terminal is a copper bus bar strapped over the top of the module. Teflon sleeve is threaded through each module for easy installation of the primary windings.

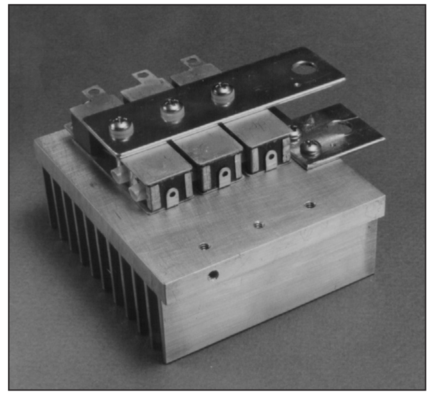


Fig. 14. Three modules of FTI-12 x 2A-1A "A" FTT KIT # 1

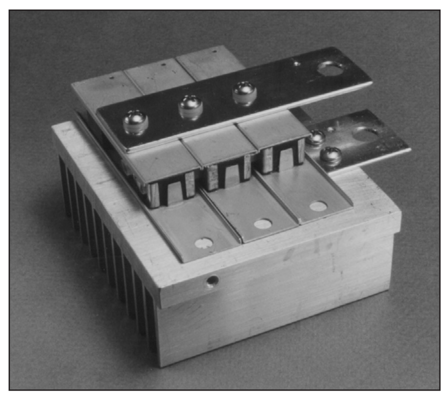


Fig. 15. 3 modules of FTI-12 x 2A-1B with power and ground copper bus bar "B" FTT KIT # 1

FTT KIT #2 to KIT # 5

Figure 16, 17, 18, and 19 shows the picture of transformer-inductor KITs 2 to 5 respectively. These kits have five modules connected in parallel on a heat sink. KIT #3 has rectifiers, and capacitors connected which comprises the entire output stage of a power converter. KIT #4 has two passes of teflon coated wires threaded through the modules as the primary windings resulting in a turns ratio of 10:1. KIT #5 has four passes of teflon coated wires as primary windings resulting in a turns ratio of 20:1.

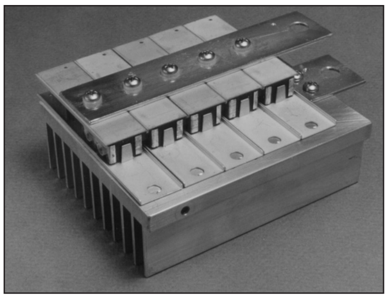


Fig. 16. "B" FTT KIT # 2

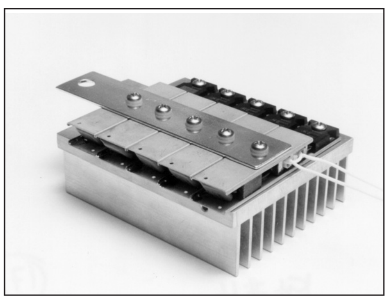


Fig. 17. "B" FTT KIT # 3

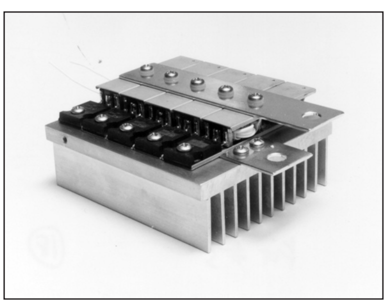


Fig. 18. "B" FTT KIT # 4

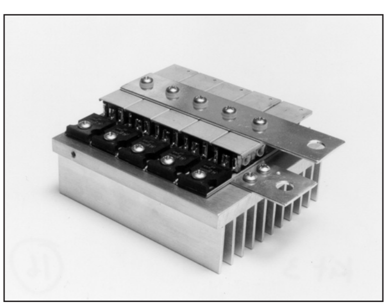


Fig. 19. "B" FTT KIT # 5

Design Guides for Buck Converters

Buck converters are step down converters. Forward, Half Bridge, Full Bridge, and Push Pull are different classes of buck converters. The FTI series modules are designed for Half Bridge, Full Bridge and Push Pull circuits. For applications in Forward topology, please contact technical support for details.

The basic buck converter circuit is shown in Figure 20.

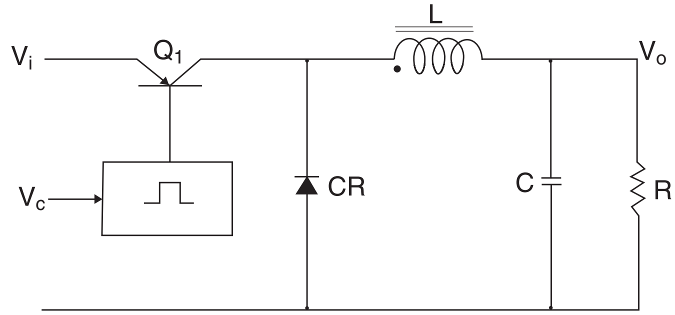


Fig. 20. Basic Buck Converter

In a buck converter, energy is stored in the output inductor during the ON time of the switch. During the OFF time of the switch, this energy is discharged to the output load through the diodes. These actions allow current to flow continuously to the load. During the ON time, the current flowing into the output inductor increases. At the instant the OFF time begins, the current flowing out of the output inductor starts to decrease. If the current did not decrease to zero level before the ON time starts again, the converter is said to be operating in the continuous mode. During the OFF time, if the inductor current is allowed to decrease to zero and stay at zero for a finite amount of time before the ON time begins, then the converter is operating in a discontinuous mode. The design examples in this application note only deals with continuous mode of operation. Additional information on converter design can be obtained from "Switch Mode Power Conversion - Analog Electronic Design Course" by K. Kit Sum.
(e-mail: kkitsum@earthlink.net for more information).
The DC transfer function for buck converters in continuous mode operation is given as:

$$V_o = D \times V_i \quad . \; . \; . \; . \quad (2)$$

Where,

D = Duty cycle,
V_o = Output voltage,
V_i = Input voltage

$$I_{min} = \frac{V_o}{R_{max}} = \frac{D_L V_i}{R_{max}} = \frac{\Delta I}{2} \qquad \text{(See Figure 21.)}$$

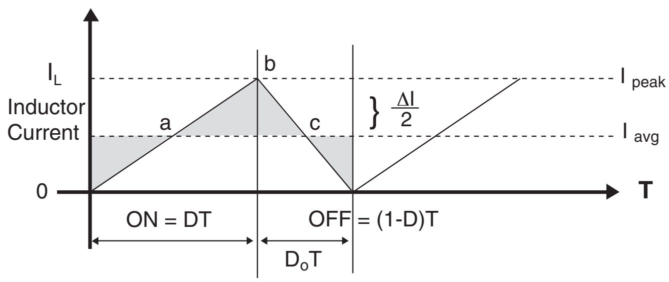


Fig. 21. Inductor current Vs time

Output Inductors

Figure 21 shows the current through the inductor. To maintain a continuous mode operation, the inductor current I_L cannot drop below zero.

Therefore,

$$I_{min} = \frac{V_o}{R_{max}} \quad .\ .\ .\ .\ (3)$$

I_{min} = Minimum Inductor Current

V_o = Output voltage,

R_{max} = Maximum load.

The voltage across the inductor is:

$$L\frac{di}{dt} = V_i - V_o = V_i\,(1 - D_L) \quad .\ .\ .\ .\ (4)$$

where,

D_L is the low duty cycle.

or

$$L\frac{\Delta I}{\Delta T} = Vi\,(1 - D_L) \quad .\ .\ .\ .\ (5)$$

The peak to peak ripple current is:

$$\Delta I = \frac{V_i\, D_L\, T\,(1 - D_L)}{L_{min}} \quad .\ .\ .\ .\ (6)$$

Since,

$$\Delta T = D_L T$$

The average ripple current =

$$\frac{\Delta I}{2} = \frac{V_i\, D_L\, T\,(1 - D_L)}{2\, L_{min}} \quad .\ .\ .\ .\ (7)$$

Hence, the minimum output inductor value is:

$$L_{min} = \frac{R_{max}\, T\,(1 - D_L)}{2} \quad .\ .\ .\ .\ (8)$$

Output Capacitors

The charge in output capacitor is the area under the triangle a, b, c in Figure 21.

Therefore, ΔQ is:

$$\Delta Q = \frac{1}{2}\left(\frac{1}{2}DT + \frac{1}{2}D_OT\right)\left(\frac{1}{2}\Delta I\right) = \frac{T\Delta I}{8} \quad .\ .\ .\ (9)$$

Therefore, the output ripple voltage is given by:

$$V_o = \frac{\Delta Q}{C} = \frac{T\Delta I}{8\,C} = \frac{V_o T^2 (1 - D_L)}{8\,L\,C} \quad .\ .\ .\ .\ (10)$$

The total capacitor value required to achieved the required ripple voltage is:

$$C = \frac{V_o T^2 (1 - D_L)}{8\,L\,\Delta V_o} = \frac{T^2 (1 - D_L)}{8\,L} \bullet \frac{V_o}{\Delta V_o} \quad .\ .\ .\ (11)$$

ΔV_o = Output ripple voltage

The capacitance calculated above is the minimum theoretical value, neglecting the effect of equivalent series resistance.

FLAT TRANSFORMER TECHNOLOGY CORP., 240 Briggs Ave., Costa Mesa, CA 92626
Tel.: 714-850-7320 Fax: 714-850-7321 www.flattransformer.com

Half Bridge (HB) Converter Design Example

A typical schematic of the HB circuit is shown in Figure 22.

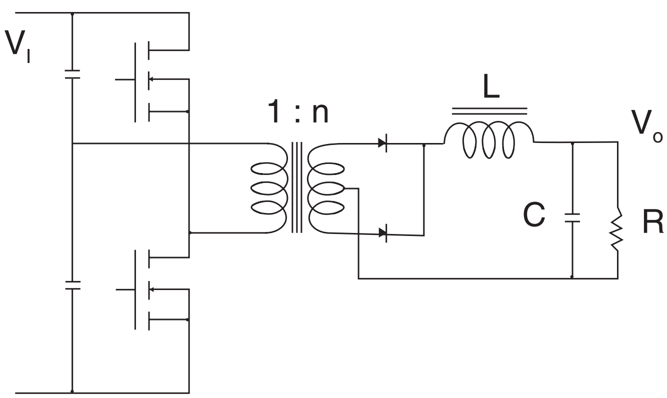


Fig. 22. Typical Half Bridge Circuit

In a conventional circuit representation, the inductor is on the positive side of the output terminal. In actual case, it does not make any difference if the inductor is connected to the positive or ground side of the output terminal. For ease of manufacturing, the output inductor of the FTI module is connected to the ground side of the output terminal.

Figure 23 shows a HB schematic using a single FTI-12x2A-1B module. The transformer has an inductance of 6.8 µH per turn squared. The built in inductor has a value of 2.2 µH at zero amps and 1.4 µH at 20 amps.

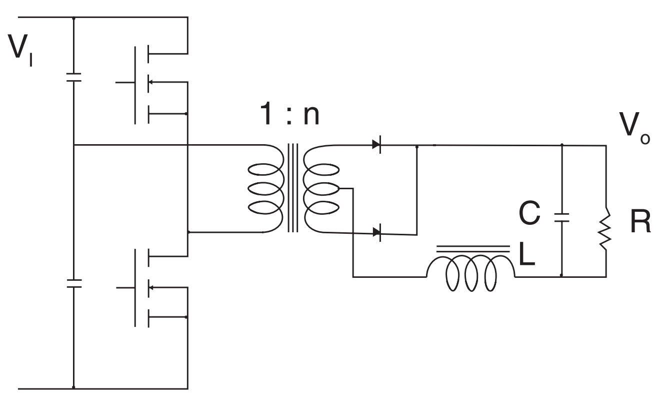


Fig. 23. HB Circuit using single FTI-12x2A-1B

If three modules are used, as in KIT #3, the modules are connected in parallel (Fig. 24). The total output current in such a configuration is a sum of currents from each module. This equal current sharing characteristic is inherent in this approach of designing transformers and inductors. Therefore, for a three module configuration, each module only need to carry 1/3 the output current load. Similarly, in a five modules configuration (FTT KIT #2 to 5), each module needs to carry 1/5 the output current load.

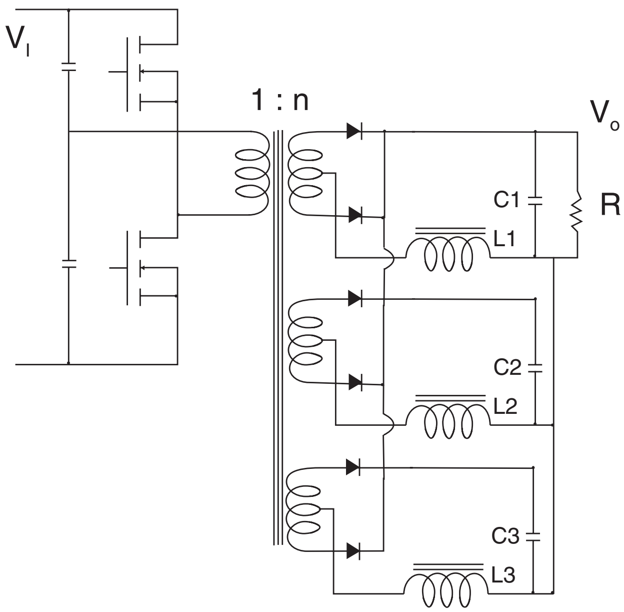


Fig. 24. HB Circuit using 3 modules of FTI-12x2A-1B

Referring to Figure 24, the parallel connection of the module causes the inductors L1, L2, L3 to be in parallel too.

Half Bridge Design Example

Let,

$V_{out} = 5$ V, $I_o = 60$ amps, f = 300 KHz and up,

Input: 240 Vdc to 375 Vdc

Output Power = 300 watts

Assume a diode drop of 1v, then $V_o = 6$v

Assume a 10% minimum load,

$I_{o\ min} = 6$ amps. $R_{max} = 5/6$ ohms

$V_{I\ max} = 375$ Vdc, $V_{i\ min} = 240$ Vdc

For Half Bridge converter, only $\frac{1}{2}$ of Vi is received by the primary side of the transformer.

$$\frac{Vo}{\frac{1}{2}V_{i\ min}} = nD_H$$

Initially, assume the high duty cycle $D_H = 0.8$ over 1 cycle, from the above equations, turns ratio, n, is $\frac{1}{16}$.

When the FTI modules are connected in parallel,
n, the turns ratio = M x N, where M is the number of modules connected together, and N is the number of passes through all the modules (or the number of turns).

To achieve a turn ratio of 16:1, the number of modules used (M), must be a multiple of 16. In this case, either 2, 4, 8, or 16 modules can be used. If two modules are used, then the number of passes (N) is 8 (2x8 = 16). Since the output current is 60 amps, two modules would mean 30 amps per module.

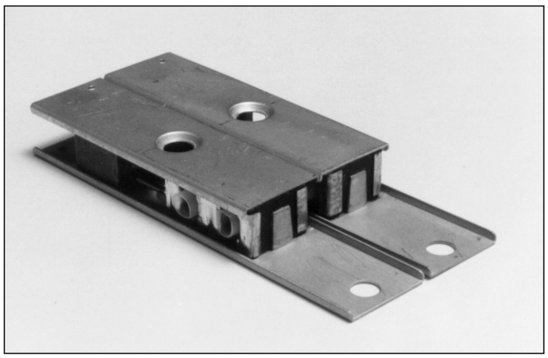


Fig. 25. Using 2 Modules: 8 passes (turns)

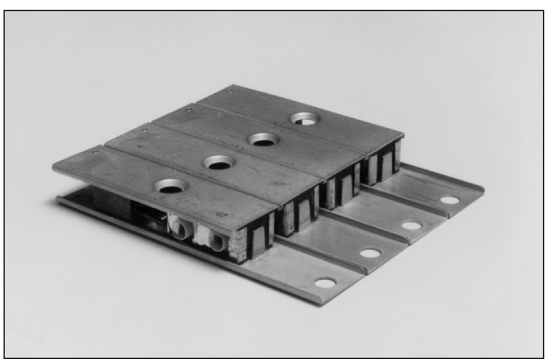


Fig. 26. Using 4 Modules: 4 passes (turns)

In this design example, we ***arbitrarily*** choose to design with 20 amps per module with three modules using KIT #1. In this case, a turns ratio of 16:1 cannot be achieved, as 16 is not a multiple of 3. A turn ratio of 15 will be used with five passes over each of the three modules (MxN = 3 x 5).

Re-calculating the above, with n = $\frac{1}{15}$,

$$\frac{6}{120} = D_H \left(\frac{1}{15}\right),$$

$$D_H = 0.75.$$

We will use a 75% duty cycle at low line (240v).
To calculate duty cycle at high line,

$$\frac{V_o}{\left(\frac{1}{2} V\, i_{max}\right)} = nD_L \;, n = \frac{1}{15} \;,$$

$$\frac{5}{187} = nD_L,\; D_L = 0.4$$

Hence, with n = $\frac{1}{15}$, the duty cycle ranges from 0.4 to 0.75.

Flat Transformer Analysis

To recap, the windings and turns ratio are as follows:

Turns ratio, n = 15:1
Number of FTI-12x2A-1B module used, M = 3
Number of passes or turns, N = 5

From Table 1 the transformer primary magnetization inductance = N^2 x M x A_L = 25 x 3 x 6.8 = 510 µH
Transformer secondary inductance = 6.8 µH

Primary windings current in the transformer = $\frac{\text{Input power}}{\text{Input Voltage}}$

in the transformer. The input power is approximated at 120% of the output power. Transformer input voltage is approximated at V_o x $\frac{1}{n}$.

Hence, primary winding current = $\frac{360}{90}$ = 4 amps.

For Flat Transformer, a minimum of 50 circular mils (2.554 mm^2) per amps is required for the primary windings. For a conventional transformer design, a typical minimum wire size is 500 circular mils per amp. Due to uniform thermal loading and the absence of bulk windings, the wire size for primary windings is $\frac{1}{10}$ to that of the conventional design.

At 4 amps, the minimum wire size is 200 circular mils. For a safety factor of two, the wire size selected is 400 circular mils or 10.2 mm^2. This is equivalent to AWG #24.

Teflon coated, triple insulated or thermoleze wires are recommended for good dielectric isolation. The isolation between the primary and secondary windings already has a layer of teflon sleeve. A dielectric breakdown of 40,000 volts between primary and secondary windings is possible with these configurations.

When the input windings are completed, it is recommended that the 2 input leads are twisted, but kept short.

Leakage Inductance

The leakage inductance per module = 4 nH per turns squared. Since five turns are used, the leakage per module is = 5^2x4 nH = 100 nH. With three modules used, the total leakage inductance is calculated to be 100x3 = 300 nH. This leakage is many times less than comparable low profile transformers. The ratio of magnetization inductance to leakage inductance is:

$$\frac{502.5\ \mu H}{300 \times 10^{-3}\ \mu H} = 1673$$

Output Inductor Analysis

Since three modules are used, and each module will be handling 20 amps, the inductance of the output inductor with 20 amps of DC bias is 1.4 µH. See Table 2. With three modules connected in parallel as in KIT #1, the resultant net inductance is = 0.466 µH (1.4/3).

Using Equation (8) for minimum inductance,

$$L_{min} = \frac{R_{max}\, T\, (1-D_L)}{2}$$

Therefore,

$$T = \frac{2 \times 0.466}{(0.6 \times 0.8333)} = 1.86\ \mu s.$$

Hence,

the optimal operating frequency is $\frac{1}{T}$ = 536 kHz.

If the design engineer desires to have the operating frequency at 300 kHz, then the following design approach can be taken. At 300 kHz, T = 3.33 µs.

Since the built-in inductance from iron powder core is 0.466 µH, an additional inductance of 0.34 µH (L_4) is required at the output. See Figure 27.

Alternatively, use the higher inductance built-in inductor using MPP or Sendust material. Call factory for details.

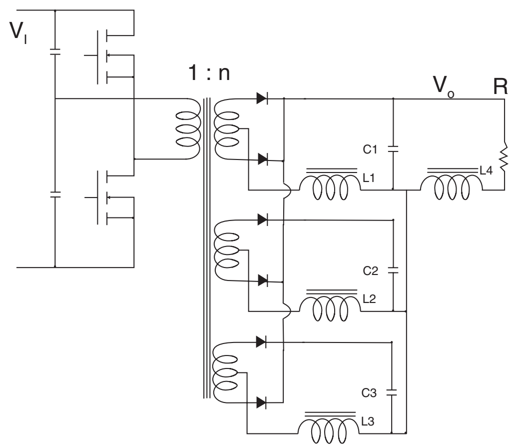


Fig. 27. HB Circuit using 3 modules with additional Inductor, L4

Output Capacitor

Same profile capacitors should be used at the output of the FTI-12 x 2A-1B module. Direct connecting points are provided at the tail end of the module. Low ESR multi layer ceramic capacitors are recommended. Flat Transformer Technology stocks MARCON's 22µF, 50v MLC capacitors that are available for engineering prototyping.

In this design example, with one 22 µF, MLC capacitors connected to each of the three modules, the total capacitance value is 66 µF.

Assume that the switching frequency selected is 550 kHz (T = 1.8 µs).

From equation 11, the output ripple voltage,

$$\Delta Vo = \frac{5 \times (1.8 \times 10^{-6})^2 \times 0.6}{(8 \times 0.466 \times 10^{-6}) \times 66 \times 10^{-6}}$$

$$= 0.039\ v \text{ or } 39\ mV \text{ peak to peak.}$$

Flux densities and Losses calculations

To calculate the flux density of the transformer, one can use either the primary or the secondary windings since flux generated by primary winding equals to flux generated by secondary winding. In the FTI series, the secondary winding is always one, so we choose to use the secondary windings in calculating the transformer's operating flux density.

$$B_{peak} = \frac{V_o \times 10^8}{(4 A_e N F)} = \frac{6 \times 10^8}{(4 \times 0.68 \times 1 \times 550 \times 10^3)}$$

$$= 401 \text{ gauss} = 40.1 \text{ mT.}$$

Since the maximum flux density of the transformer is 450 mT, the transformer is operating at only 10% of the flux capacity.

From the transformer loss curve of Graph 1, at 550 kHz, and 40 mT, the total core plus winding loss is estimated to be 200 mW per module.

With three modules, the total transformer core loss is **600 mW.**

The flux density of the inductor can be also be represented as:

$$\Delta B_{peak} = \frac{V_o \times 10^8}{(4 A_e N F)} ,$$

but for the ease of calculation of losses in inductor, the above formula can be presented in another manner,

$$\Delta B_{peak} = \frac{V_{peak} \times 10^8 \times D}{(2 A N)} = \frac{L \times \Delta I \times 10^8}{2 A_e N} ,$$

where ΔI is the peak to peak ripple current, D = ON time of the cycle, assume at 50% duty cycle, L = net inductance, A_e = inductor cross sectional area, V_{peak} = peak output voltage.

$$\Delta I = \frac{V_o \; T(1-D_L)}{2L} = \frac{6 \times 1.8 \times 10^{-6} \times 0.6}{(2 \times 1.4 \times 10^{-6})} = 2.3 \text{ amps}$$

Hence,

$$\Delta B = \frac{1.4 \times 10^{-6} \times 2.3 \times 10^8}{(2 \times 0.6 \times 3.5)} = 76.6 \text{ gauss}$$

(At 20 A, L = 1.4 µH. See Table 2)

The inductor will be DC biased to 20 amps of DC current, and the flux density are due the ripple current riding on top of the DC level. Figure 28 shows the operating B-H loop due to DC bias. The DC bias on the inductor will shift the operating hysterisis B-H loop to the DC current level, but will not cause appreciable core loss. The core loss is primarily due to the flux density from the ripple current.

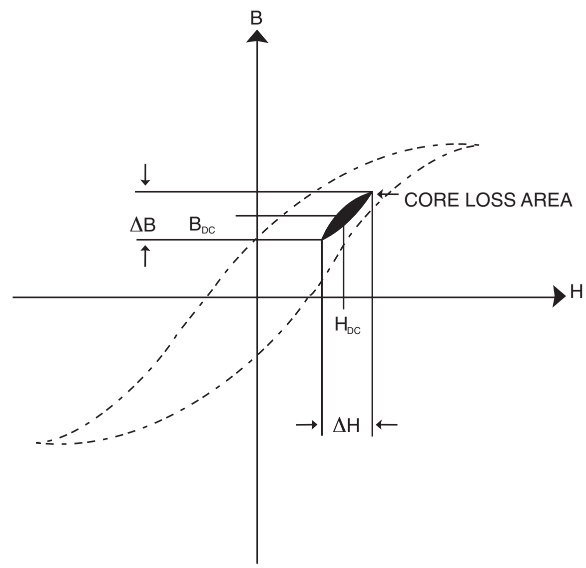


Fig. 28. B-H Showing Inductor operating with DC bias.

From the inductor core loss found in Graph 3, the inductor cores loss (hysterisis, eddy current and residual loss) is estimated to be 400 mW. Total loss for three modules is = 400 x 3 =1.2 watts.

The inductor winding loss = $I^2 R$. In this case, I is the DC bias current of 20 amps in each module. From Table 2, the DC resistance of windings in inductor is: 0.132 mΩ/cm. The wire length used in the inductor is 18 cm.

Winding loss = $20 \times 20 \times 0.132 \times 10^{-3} \times 18 = 0.95$ watts.

The total winding or copper loss = 3 x 0.95 = 2.85 watts

Total inductor plus winding loss is: 2.85 + 1.2 = 4.05 watts

The total module loss = 0.6 + 1.2 + 2.85 = 4.65 watts

The design example shows that the highest loss is the inductor windings or copper loss. The heat generated in the inductor's winding is sinked away by the top plates where the inductor windings are connected. Therefore, the overall temperature rise is still quite low compared to any other conventional type of transformer and inductor in the market. If MPP or Sendust type inductor core is selected, the losses will be much lower.

Efficiency,

$$n = \frac{Po}{PI} = \frac{Po}{(Po + \text{total loss})} = \frac{300}{304.65} = 98.5\%$$

However, the efficiency of the transformer itself is

$$\frac{300}{300.6} = 99.8\%,$$

without accounting for output inductor loss.

Additional Information

For more information or other design examples, please contact our technical support at ***jlau@flattransformer.com*** or visit our web site at ***www.flattransformer.com***.

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