NEW TRENDS IN MAGNETIC TECHNOLOGY

Ionel Dan Jitaru

Delta Energy Systems (Arizona) Inc.
4400 E. Broadway, Suite 803
Tucson, Arizona 85711

OUTLINE

- **Controlling the Leakage Inductance**
- **Minimization of The Gap Effect**
- **Quasi-integrated Magnetic**
- **Integrated Magnetic**
- **New Distributed Magnetic Structures for High Efficiency**
- **Example of Magnetic Optimization**

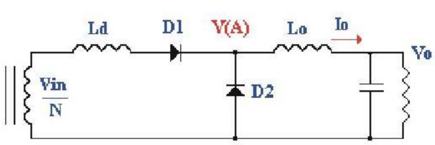
DES Arizona Inc..
Tucson, Arizona

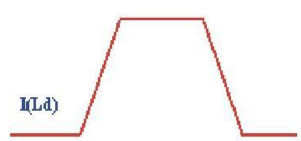
Energy Systems

CONTROLLING THE LEAKAGE INDUCTANCE

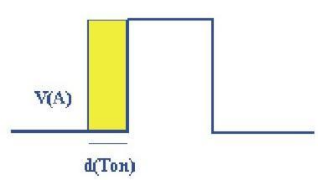
Energy Systems

THE EFFECT OF PARASITIC INDUCTANCE

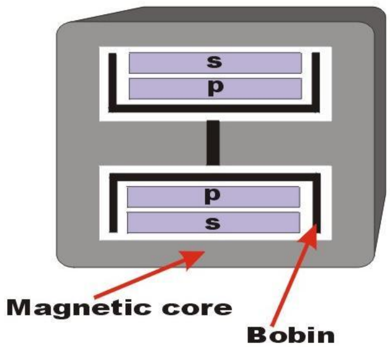


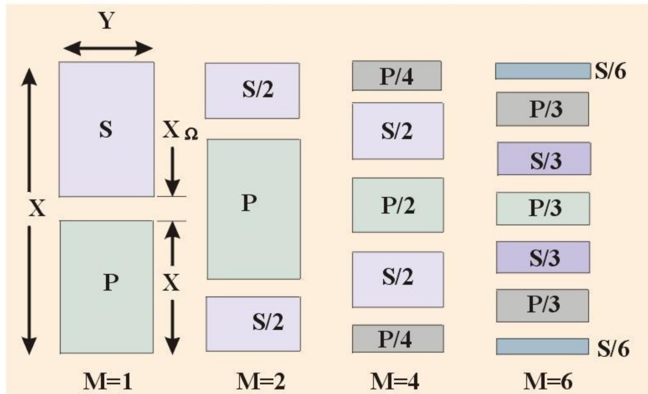


$$\triangle D = Ld \cdot Io \cdot Freq \cdot \frac{1}{\frac{Vin}{N}}$$



HOW TO MINIMIZE THE LEAKAGE INDUCTANCE

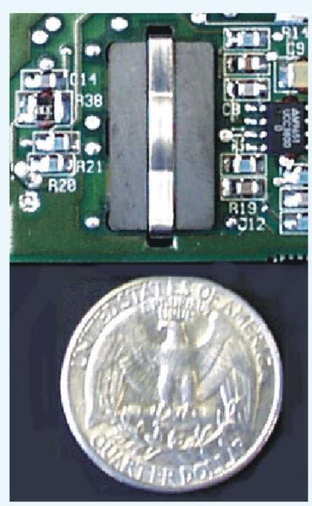




$$Llek = 4\cdot\Pi\cdot10^{-4}\,\frac{N^2\,lw}{M^2\,Y}\left(\frac{\Sigma x}{3} + \Sigma\,x\Delta\right)$$

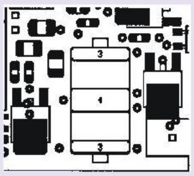
[20]

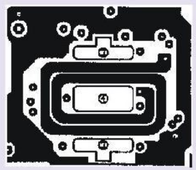
TOP AND BOTTOM LAYERS OF THE 25W DC-DC FLYBACK CONVERTER

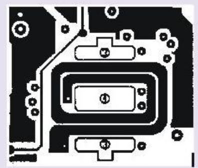


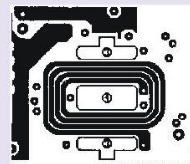
[7]

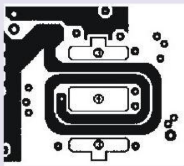
IMPLEMENTATION OF THE 25W DC-DC FLYBACK CONVERTER

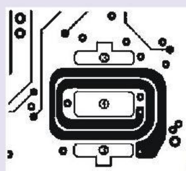

Layer 1: Components

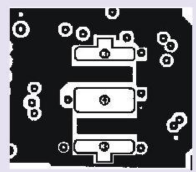

Layer 2: Secondary

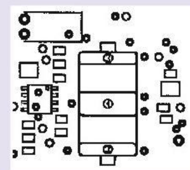

Layer 3: Primary


Layer 4: Secondary


Layer 5: Primary

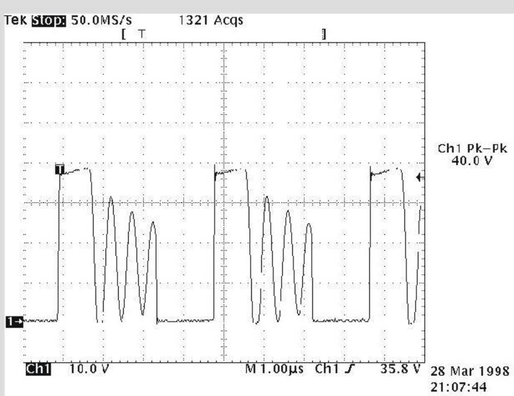

Layer 6: Secondary


Layer 7: Shield

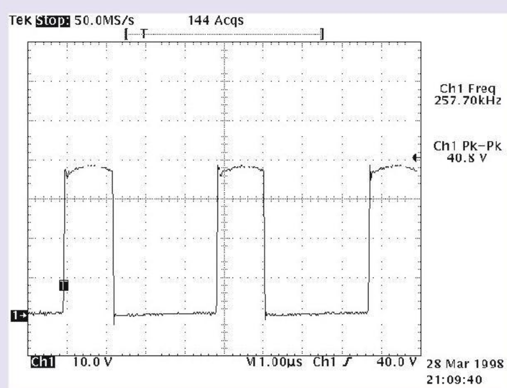

Layer 8: Components

[7]

EXPERIMENTAL WAVE FORMS OF THE 25W DC-DC FLYBACK CONVERTER



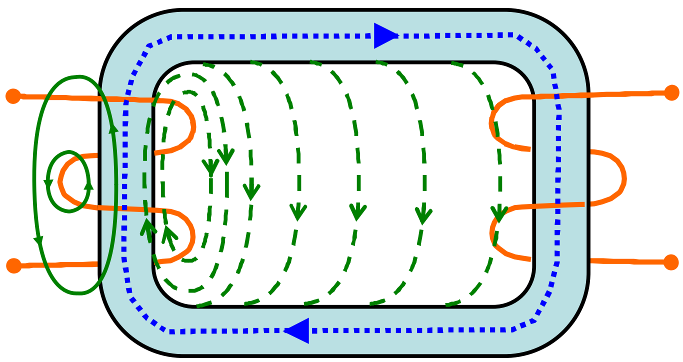
Voltage across Q1
Vin = 13.7V
Io = 0.2A



Voltage across Q1
Vin = 13.7V
Io = 0.6A

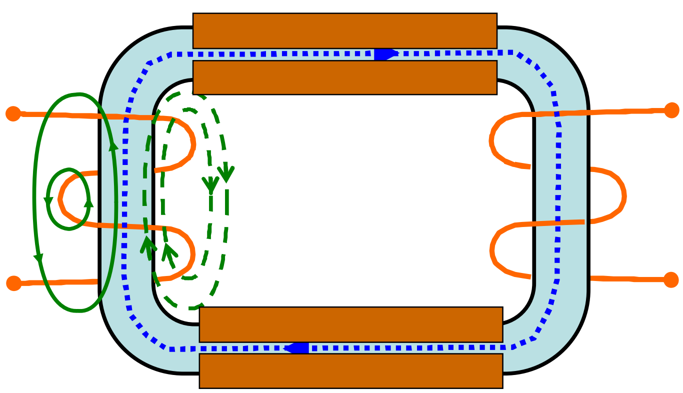
Energy Systems

Leakage Flux

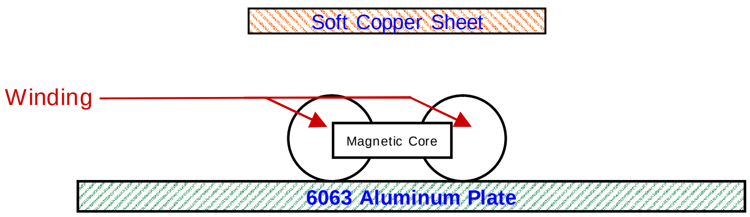


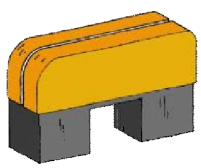
Energy Systems

Flux Tunnel



Control of Leakage Inductance



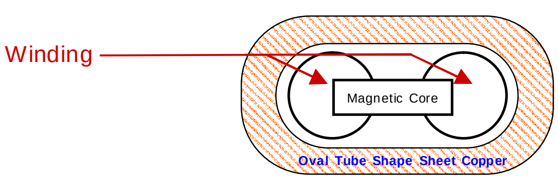


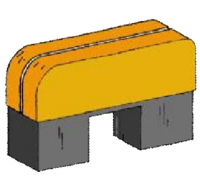
Configuration	Inductance (uHenry)	Resistance (ohms)	
No Conductive Medium	**30.3**	**1.13**	
Aluminum Plate	**21.1**	**1.15**	-30.3%
Aluminum plate on one side and Copper plate on top	**19.5**	**1.44**	-35.64%
Aluminum plate on one side and Copper plate on top & Copper Cups over both end of Magnetic core	**8.35**	**1.68**	-72.44%

[21]

DELTA Energy Systems

Control of Leakage Inductance





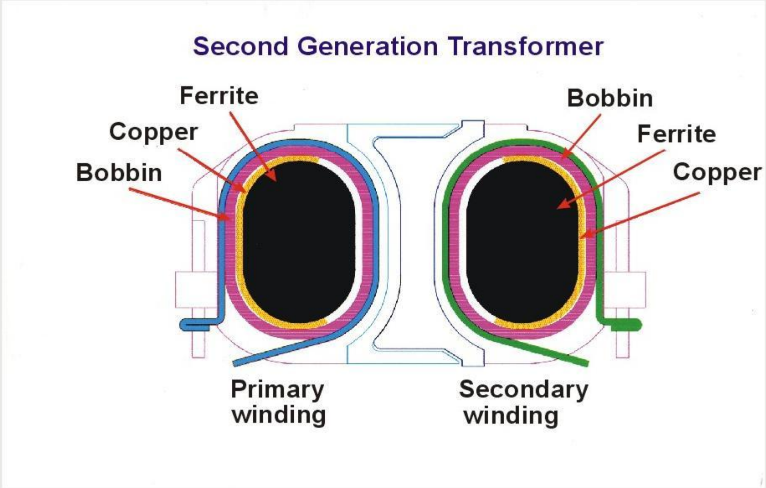
Configuration	Inductance (uHenry)	Resistance (ohms)	
No Conductive Medium	**30.3**	**1.13**	
Copper Tube Surrounding Core and Winding	**7.16**	**1.21**	-76.36%
Copper Tube Surrounding Core and Winding & Copper Cups over both end of Magnetic core	**6.46**	**1.21**	-78.67%

[21]

DELTA Energy Systems

NEW MAGNETICS STRUCTURES

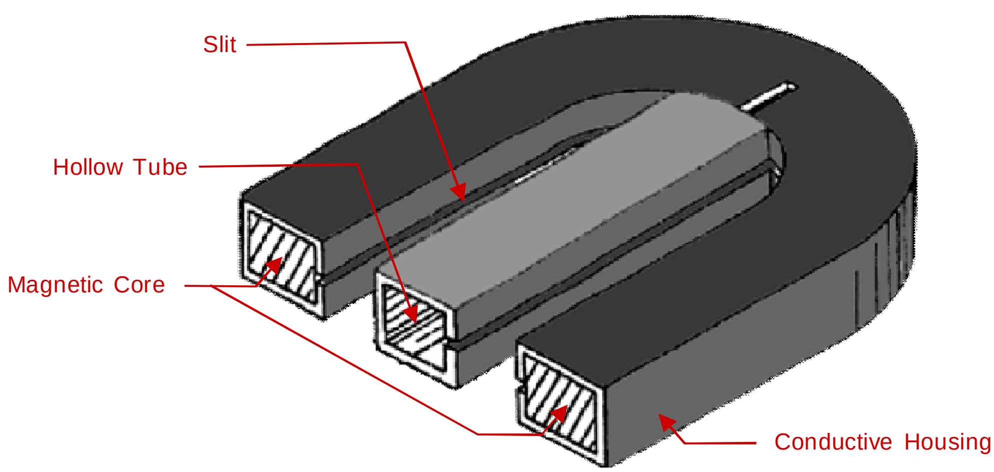
- VICOR'S "FLUX TUNNEL" FOR A CONTROL FLUX LINKAGE BETWEEN PRIMARY AND SECONDARY WINDING



[21]

DELTA Energy Systems

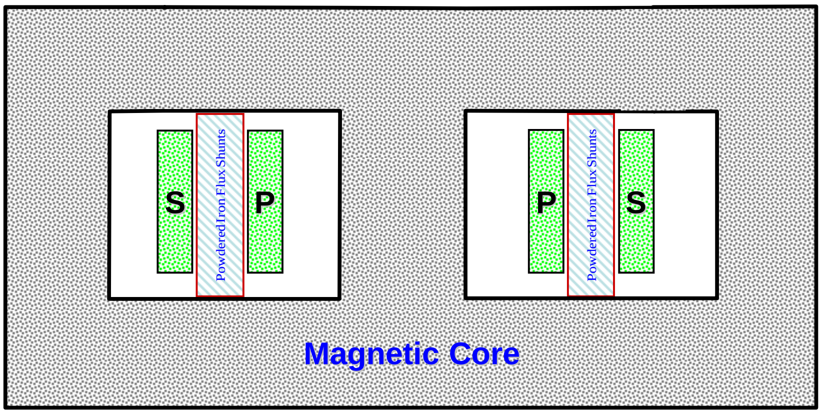
Control of Leakage Inductance



[21]

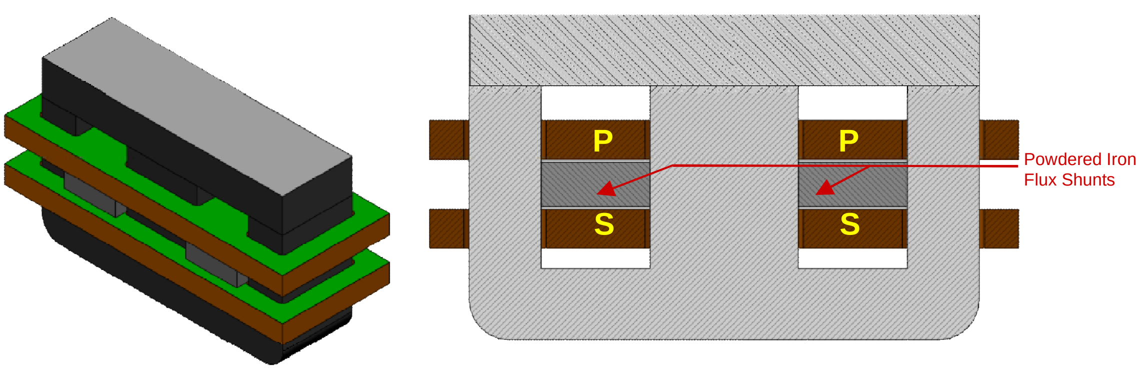
DELTA Energy Systems

Control of Leakage Inductance

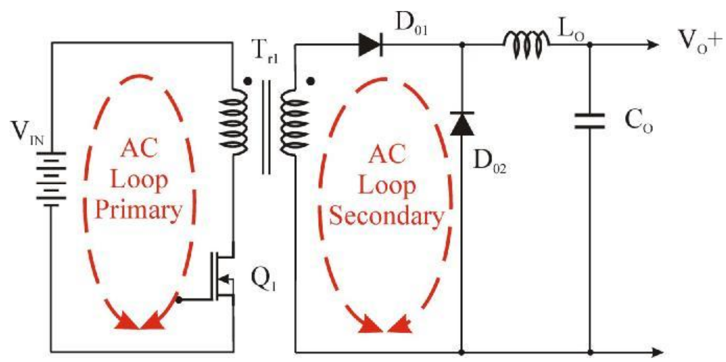


DELTA Energy Systems

Control of Leakage Inductance



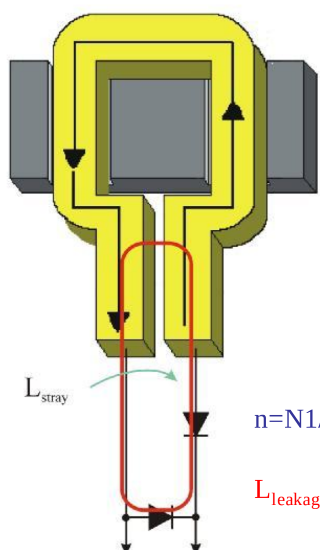
THE IMPACT OF THE STRAY INDUCTANCE

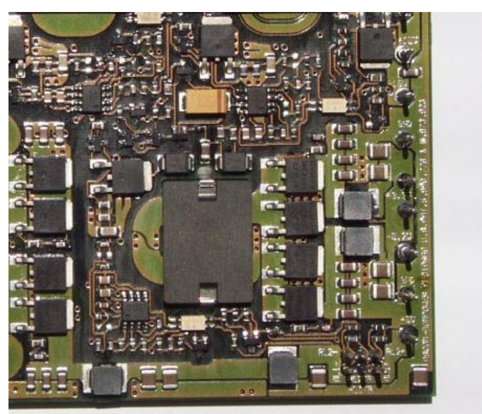


- THE STRAY INDUCTANCE ASSOCIATED WITH THE AC LOOP, PLAY A VERY IMPORTANT ROLE IN THE CONVERTERPERFORMANCE.

- THE EFFECT OF THE STRAY INDUCTANCE CAN BE STRONGER THAN THE EFFECT OF LEAKAGE INDUCTANCE.

THE IMPACT OF THE STRAY INDUCTANCE





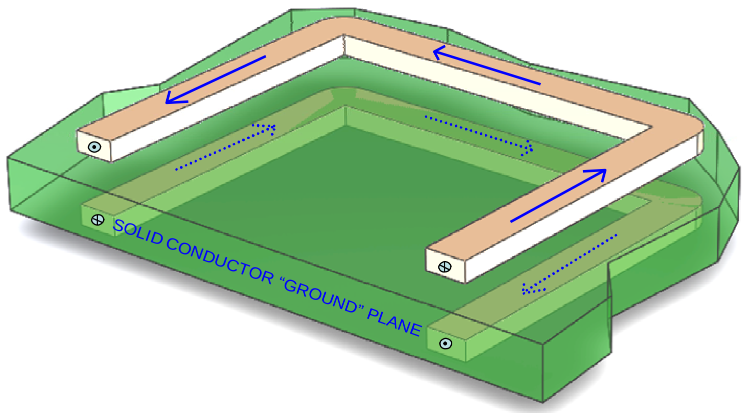
$n=N1/N2=8:1$ Leakage= 0.63uH L_{Stray}= 0.0088uH

$L_{leakage\_total} = L_{leakage} + n^2 * L_{Stray}$

$L_{leakage\_total}$= 1.2uH

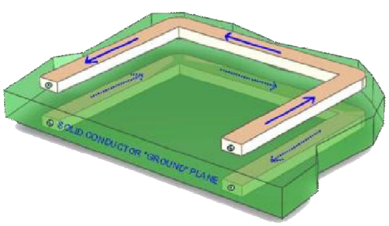
Delta Energy Systems

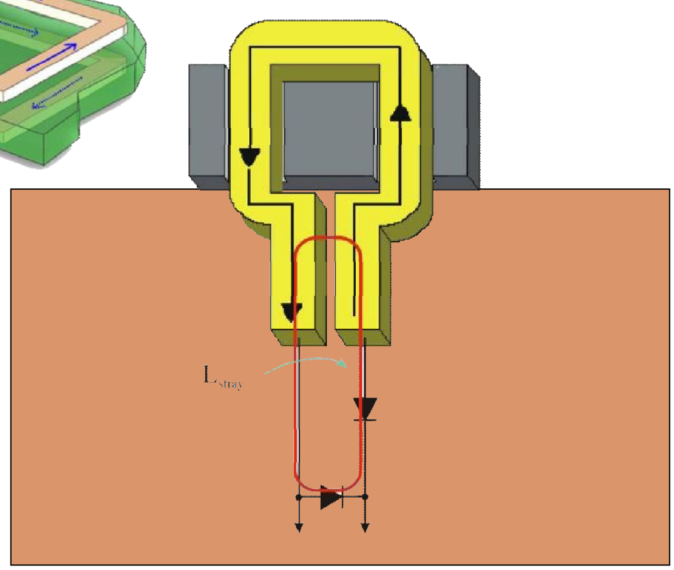
THE CONTROL OF STRAY INDUCTANCE



Delta Energy Systems

REDUCING THE STRAY INDUCTANCE





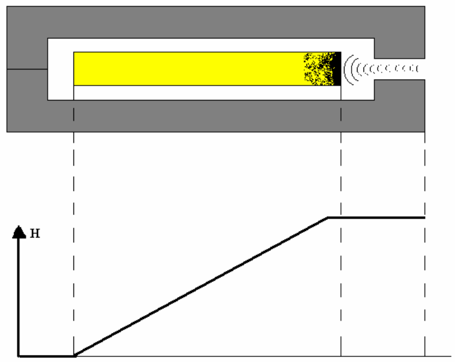
LEAKAGE INDUCTANCE - CONCLUSION

- Leakage Inductance is mainly controlled by N and M.
  - The advantage of planar magnetic
- Flux "steering" and its impact on the Leakage Inductance
- Stray Inductance impact and way to minimize it

MINIMIZATION OF THE GAP EFFECT

DELTA Energy Systems

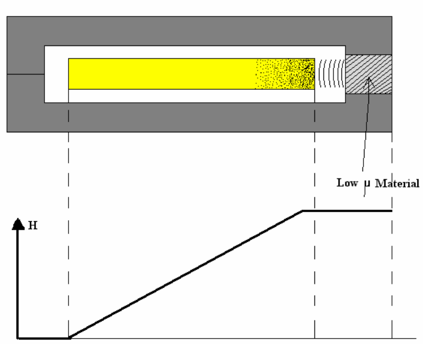
GAP EFFECT IN PLANAR MAGNETICS



- CURRENT DISTRIBUTION IN PLANAR WINDING DUE
- TO THE GAP EFFECT.

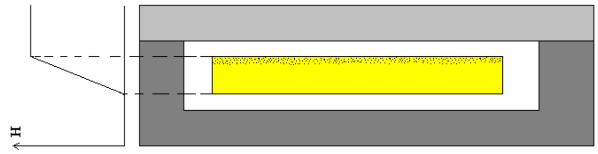
DELTA Energy Systems

GAP EFFECT IN PLANAR MAGNETICS



- THE IMPACT OF A LOW μ MATERIAL INSERT INTO THE GAP

GAP EFFECT IN PLANAR MAGNETICS



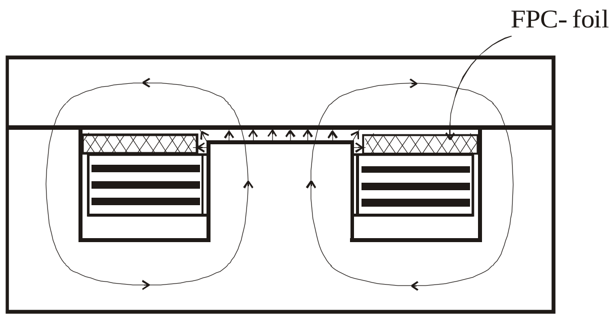
- CURRENT DISTRIBUTION IN PLANAR WINDING WHEN DISTRIBUTED GAP MATERIAL IS USED FOR THE “I” SECTION

GAP EFFECT IN PLANAR MAGNETICS

- CURRENT DISTRIBUTION IN PLANAR WINDING WHEN DISTRIBUTED GAP MATERIAL IS USED PARALEL WITH THE WINDING

DELTA Energy Systems

MINIMIZING THE GAP EFFECT IN PLANAR MAGNETICS

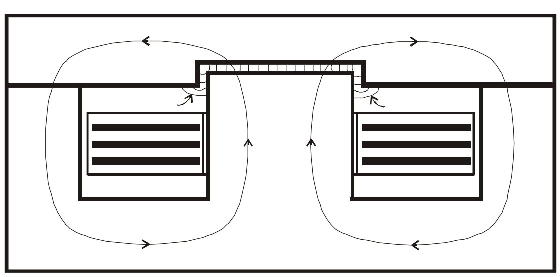


- "FORCING" THE MAGENTIC FIELD AROUND THE GAP TO BE PARALLEL WITH THE WINDING BY USING FERRITE POLYMER COMPOSITE (FPC).

[17]

DELTA Energy Systems

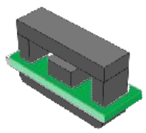
MINIMIZING THE GAP EFFECT IN PLANAR MAGNETICS

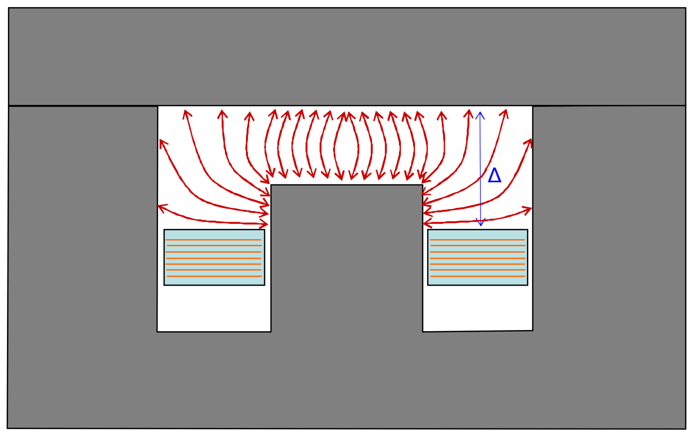


- "FORCING" THE MAGENTIC FIELD AROUND THE GAP TO BE PARALLEL
  - WITH THE WINDING.

[17]

CENTER LEG GAP

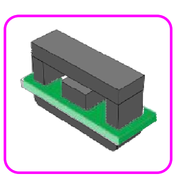


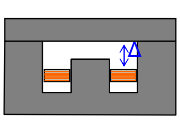


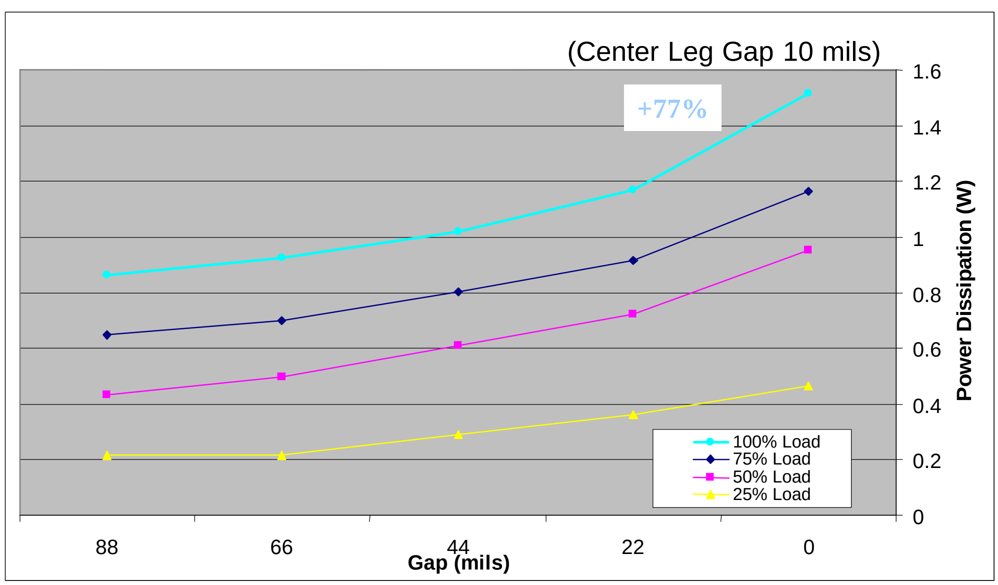
70W Flyback
Vin=80V
Vo=19V
Np=14t
Ns=2t
EQ30 / 3F35
Freq=300Khz

[13]

Power Dissipation in Transformer versus **Load and** *Distance to the Gap*

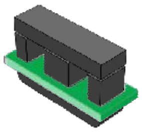


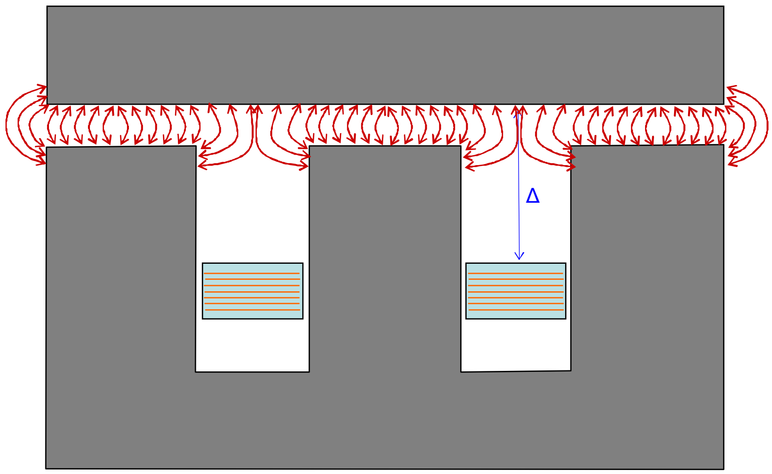




[13]

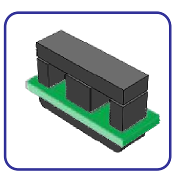
GAP IN ALL LEGS

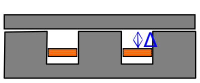


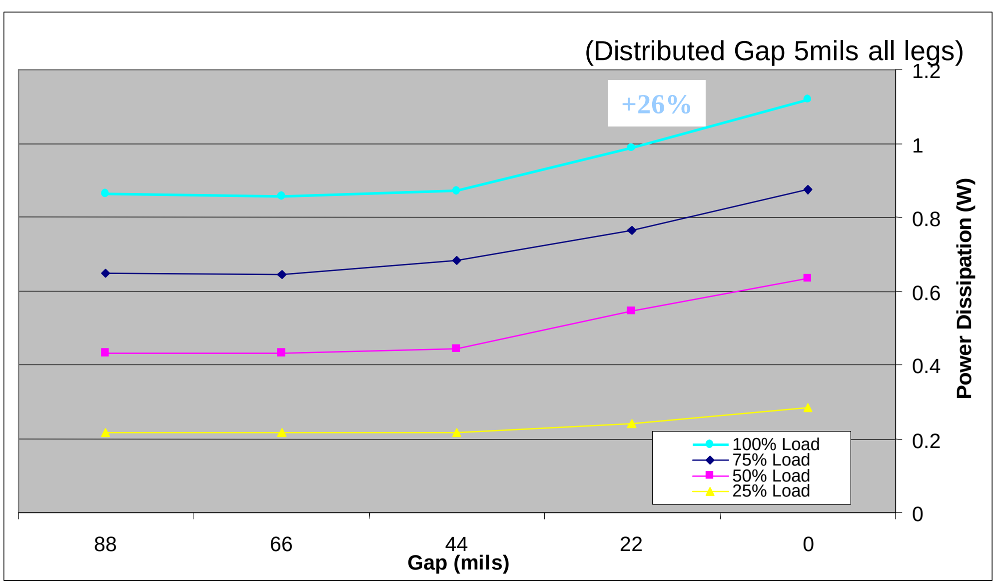


[13]

Power Dissipation in Transformer
versus **Load and** *Distance to the Gap*

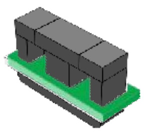


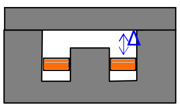


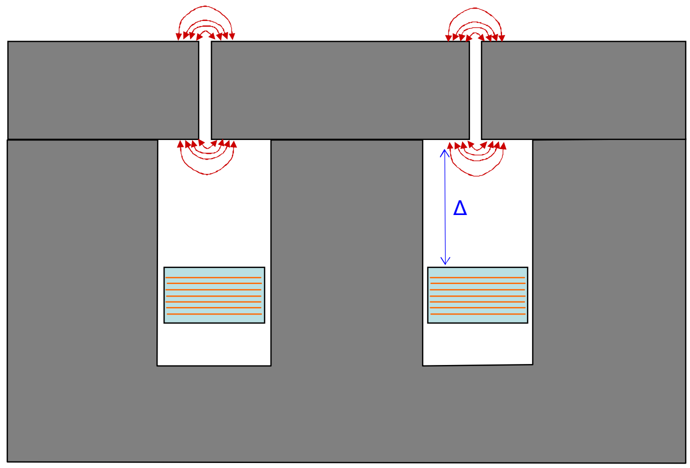


[13]

GAP IN THE I CORE

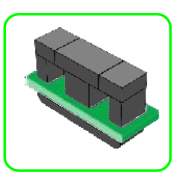


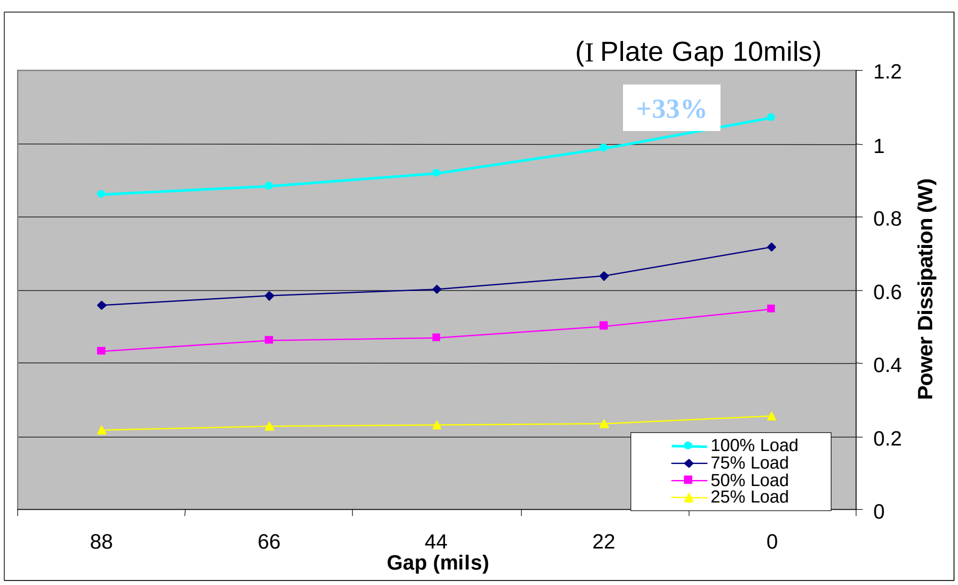




[13]

Power Dissipation in Transformer versus **Load and** *Distance to the Gap*

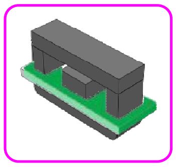


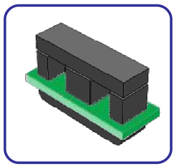


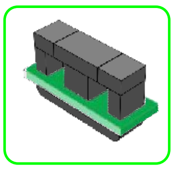
[13]

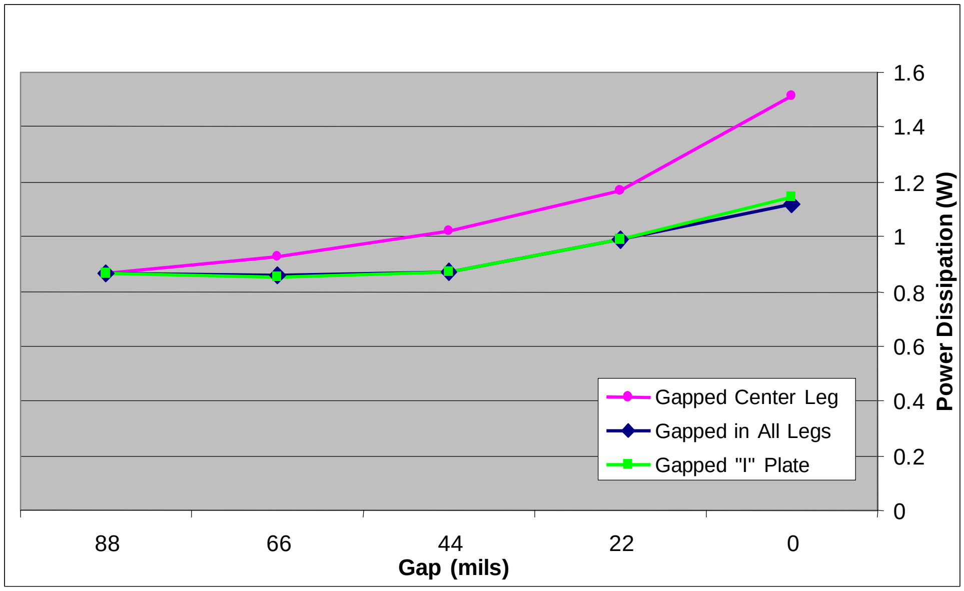
Δ DELTA Energy Systems

Power Dissipation In Transformer vs. Distance to the Gap at Full Load for Different Gapping Techniques





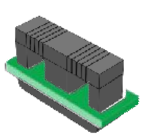


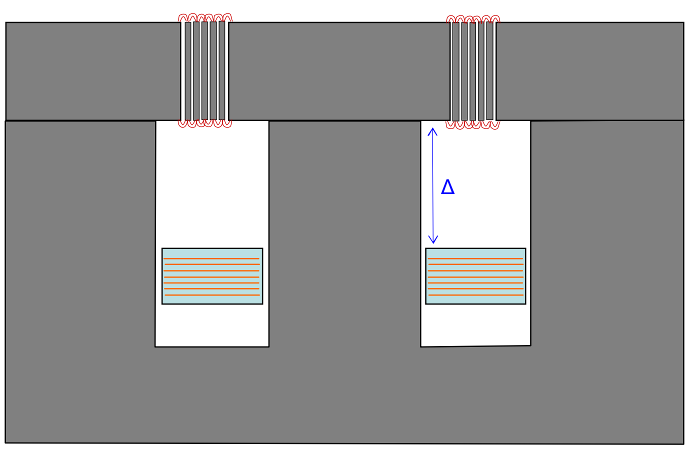


[13]

Δ DELTA Energy Systems

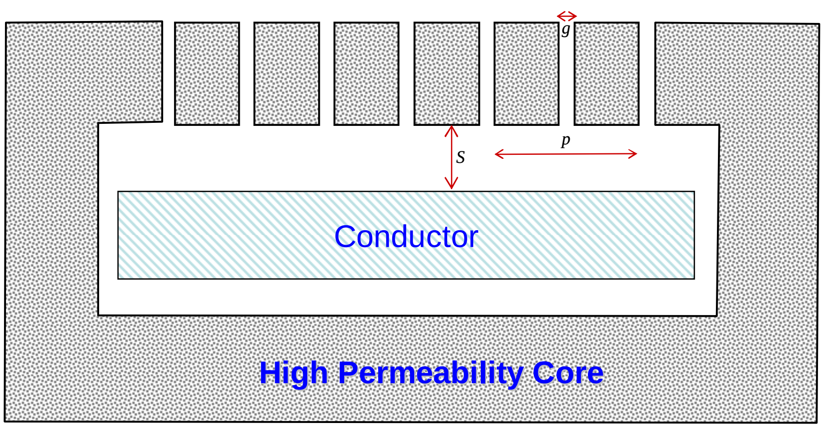
DISTRIBUTED GAP IN THE I CORE





[13]

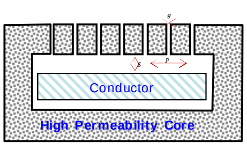
Quasi-distributed Gap

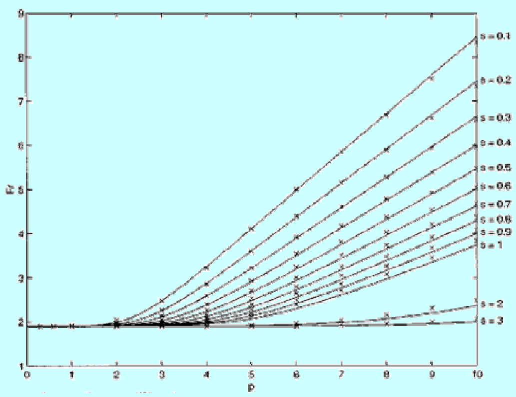


ac rez. Factor Fr=Rac/Rdc [15]

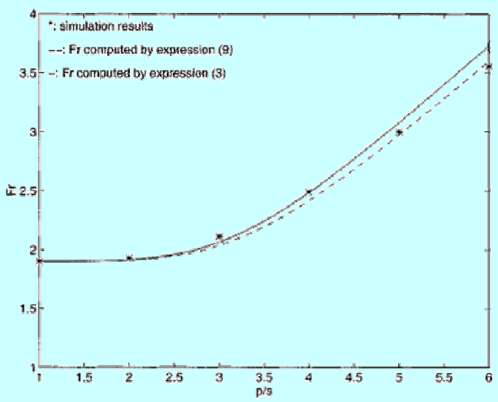
*AC Resistance of Planar Inductors and the Quasidistributed Gap Technique by Jiankun Hu/C.R. Sullivan

Quasi-distributed Gap





*Computed values of F_r



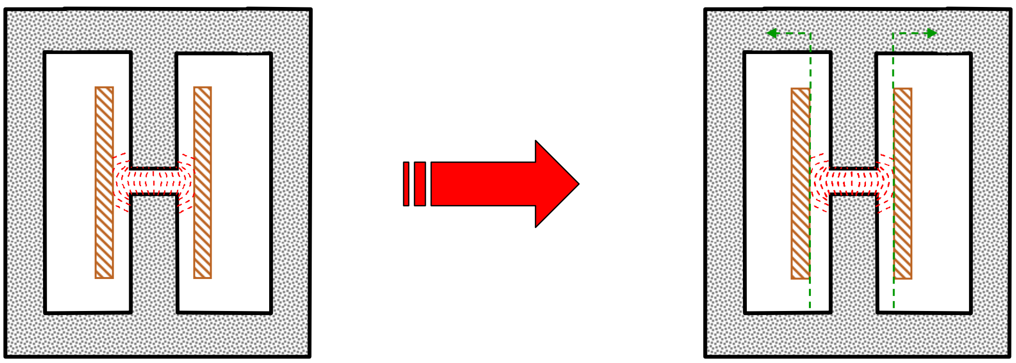
*F_r as a function of the ratio *p/s* with *s = 20.*

ac rez. Factor Fr=Rac/Rdc [15]

*AC Resistance of Planar Inductors and the Quasidistributed Gap Technique by Jiankun Hu/C.R. Sullivan

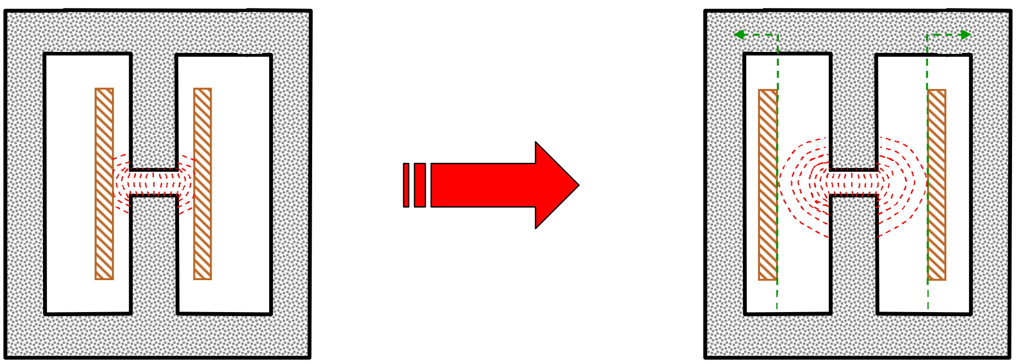
Energy Systems

GAPPING EFFECT IN NON- PLANAR MAGNETICS



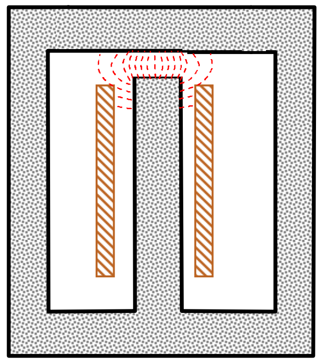
Energy Systems

GAPPING EFFECT IN NON- PLANAR MAGNETICS



Delta Energy Systems

GAPPING EFFECT IN NON- PLANAR MAGNETICS



Delta Energy Systems

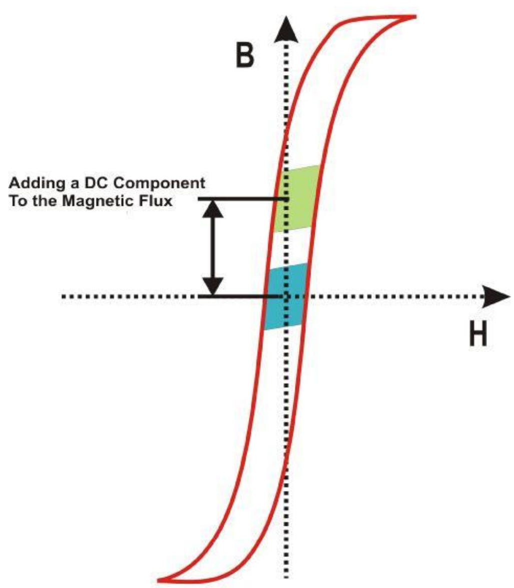
GAP EFFECT - CONCLUSION

- Gap Effect in planar magnetic
- Minimizing the Gap Effect in planar magnetic
- Quasi-distributed Gap

QUASI-INTEGRATED MAGNETIC

DELTA Energy Systems

QUASI-INTEGRATED MAGNETIC



Delta Confidential

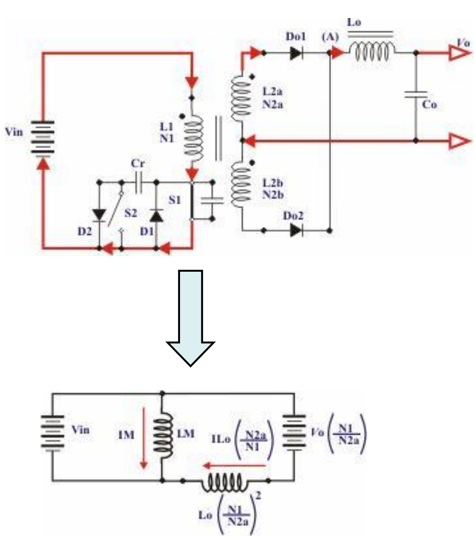
DELTA Energy Systems

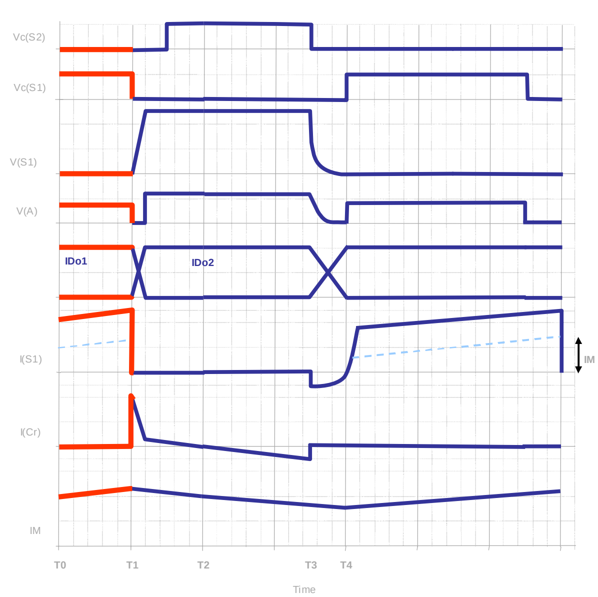
WHAT IS QUASI-INTEGRATED MAGNETIC?

- An avenue for increasing the power density through a better utilization of the magnetic core
- It is a consequence of the high switching frequency
- It can be implemented in any single ended forward with a low impedance reset path

DELTA Energy Systems

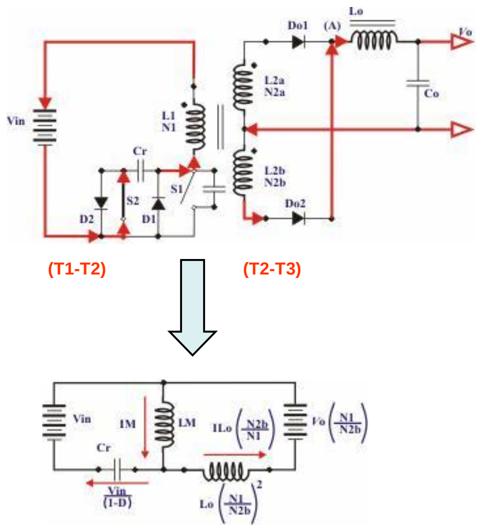
Forward Flyback / Stages of Operation Stage (T0-T1)

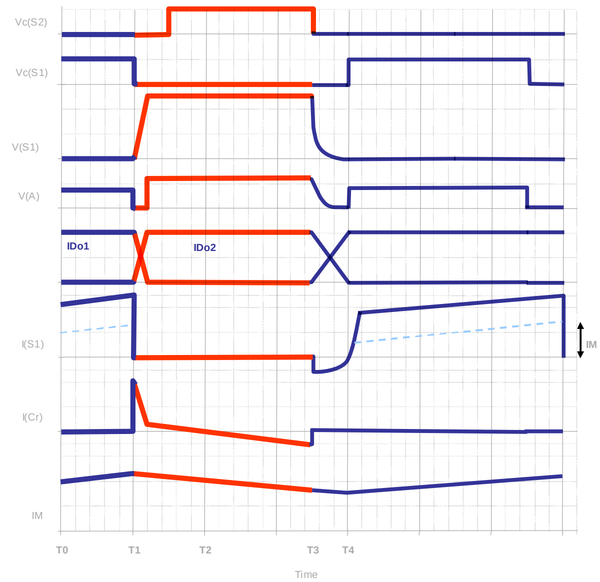




Delta Energy Systems

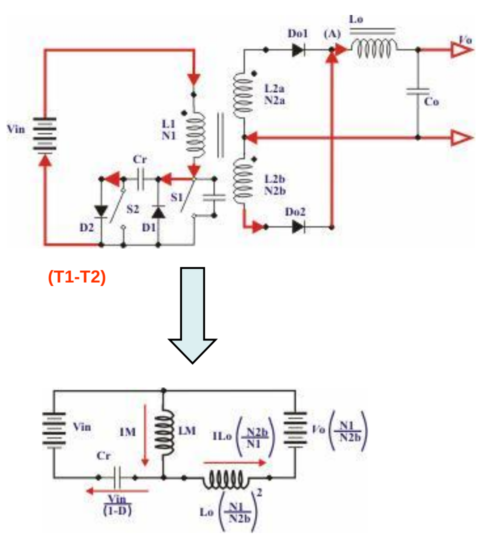
Forward Flyback / Stages of Operation
Stage (T1-T3)

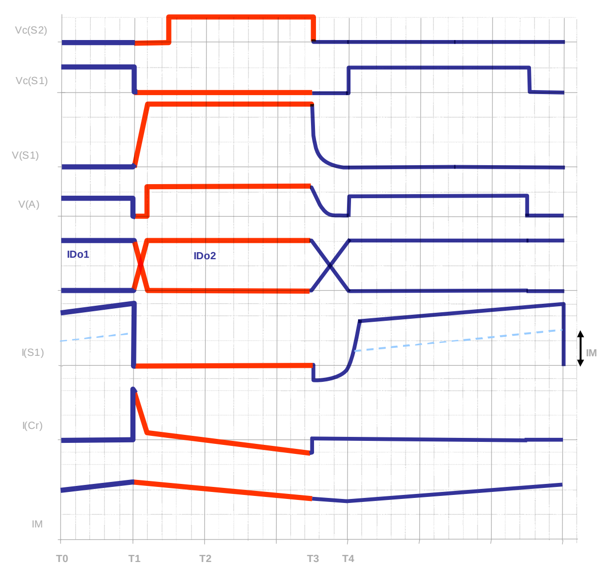




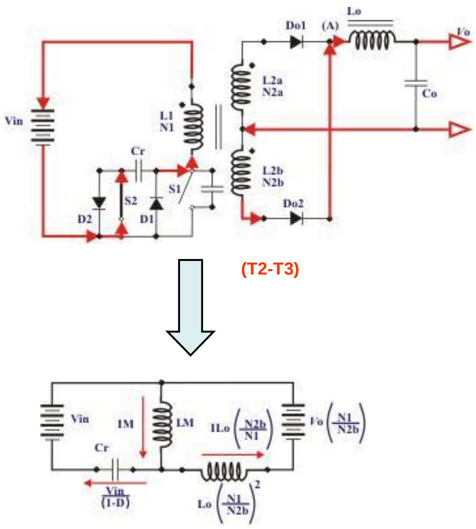
Delta Energy Systems

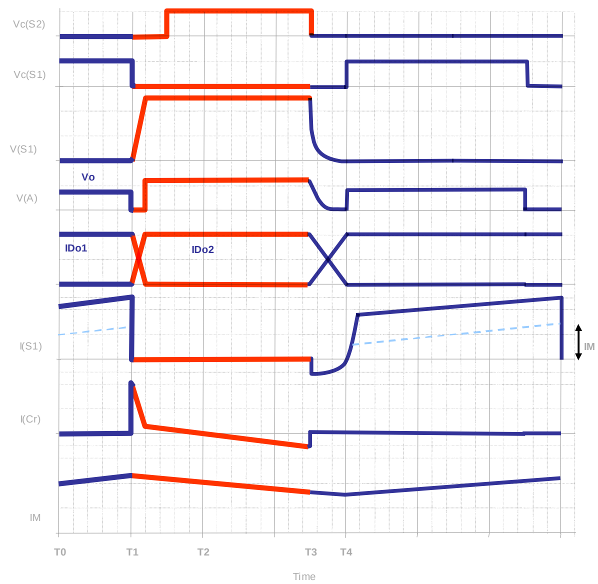
Forward Flyback / Stages of Operation
Stage (T1-T3)



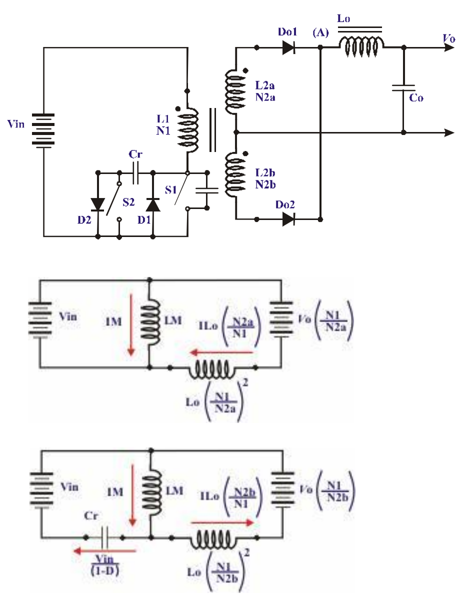


Forward Flyback / Stages of Operation Stage (T1-T3)





Forward Flyback I_M Derivation



$$I_M = IL_o(N_{2b}/N_1)$$

If $N_{2b} = (N_2/2)$

$I_M = IL_o[(N_2/N_1).(1/2)]$

If $N_{2b} = 0$

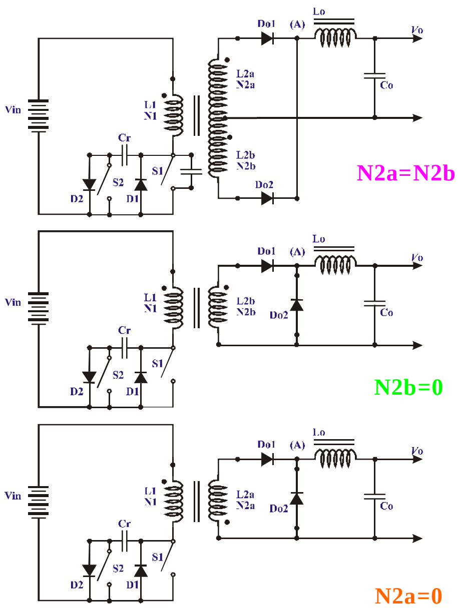
$I_M = 0$

If $N_{2b} = N_2$

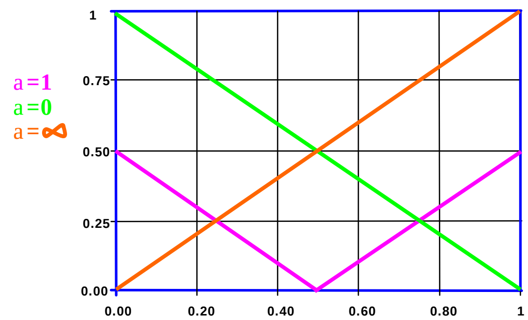
$I_M = IL_o(N_2/N_1)$

DELTA Energy Systems

Forward-Flyback Topology

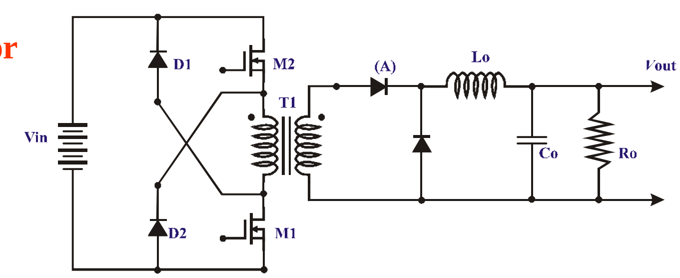


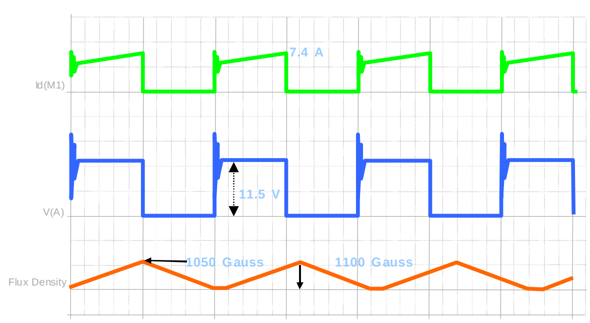
Current Ripple In The Output Inductor



DELTA Energy Systems

Two Transistor Forward



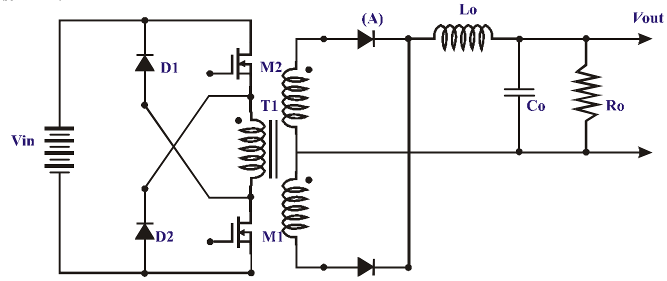


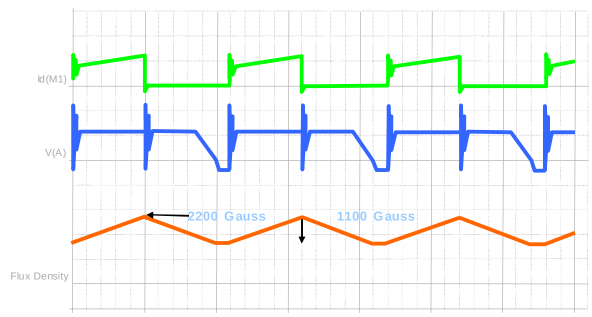
Lo=2uH
ΔI(Lo)=4.7A

Key Waveforms (100W 5V@20A)

DELTA Energy Systems

Two Transistor Forward Flyback



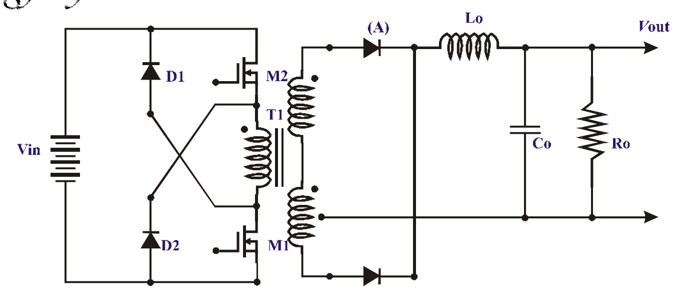


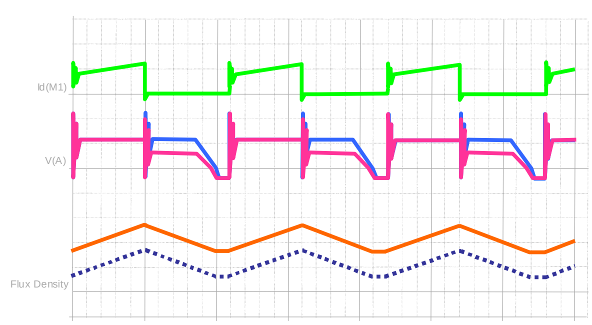
Lo=2uH
ΔI(Lo)=0.8A

Key Waveforms

DELTA Energy Systems

Two Transistor Forward Flyback





Key Waveforms

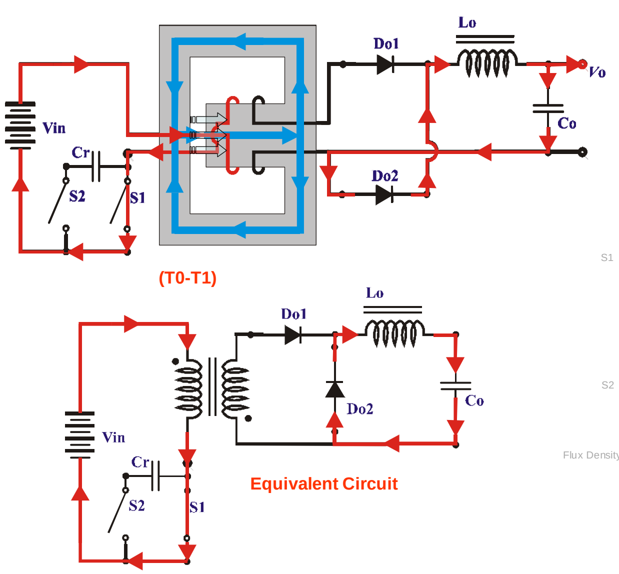
QUASI-INTEGRATED MAGNETIC

TO

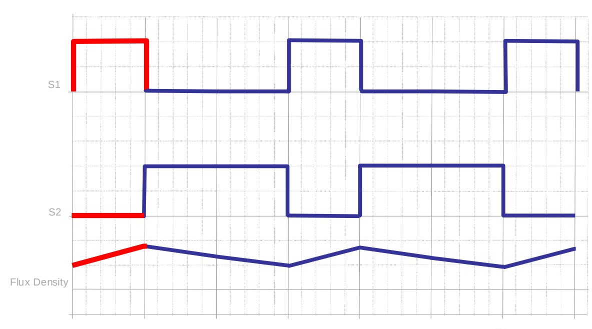
INTEGRATED MAGNETIC

Delta Energy Systems

"Current Forced" Flyback Operation Stage (T0-T1)

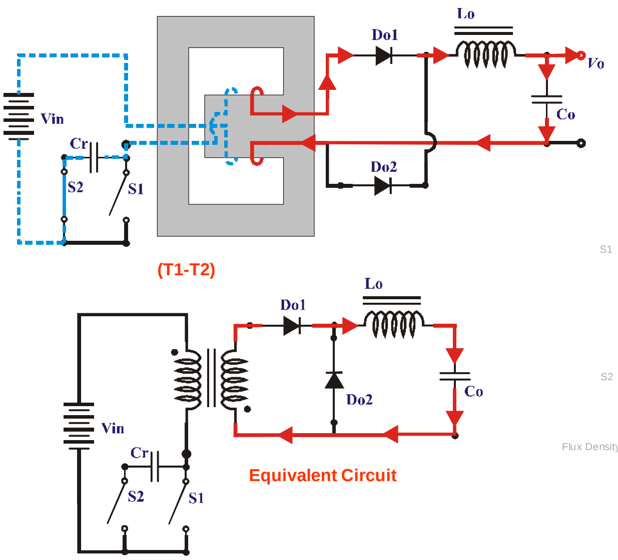


Key Waveforms at stage T0-T1

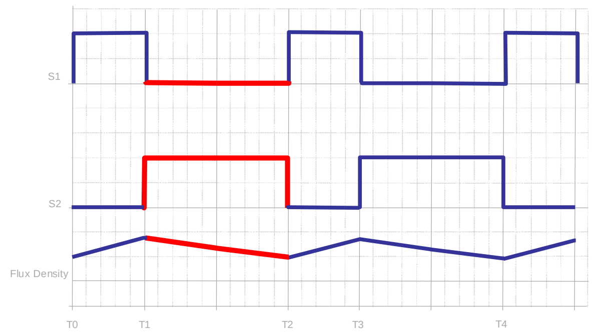


[4]

"Current Forced" Flyback Operation
Stage (T1-T2)

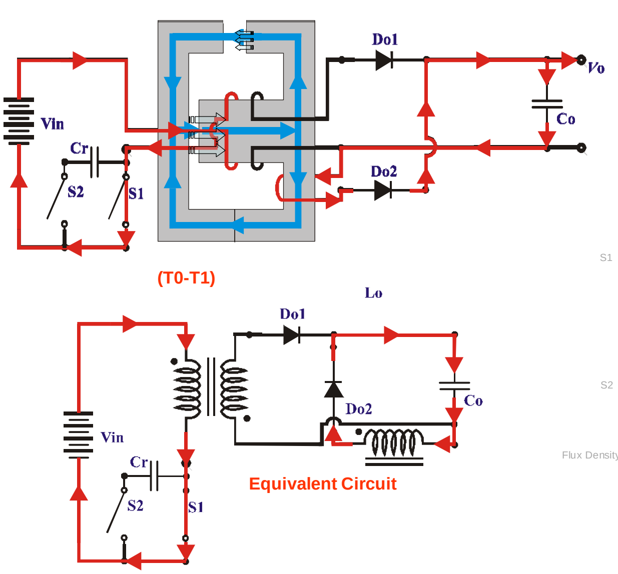


Key Waveforms at stage T1-T2

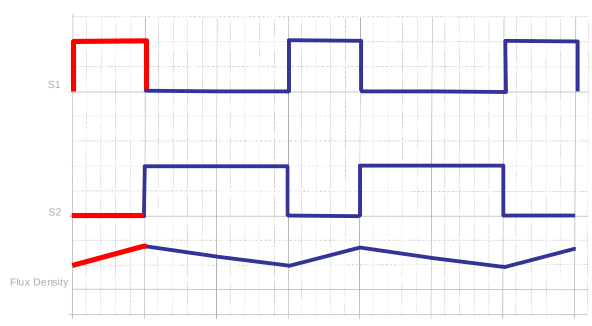


[4]

"Current Forced" Flyback with Gapped Magnetic Operation
Stage (T0-T1)

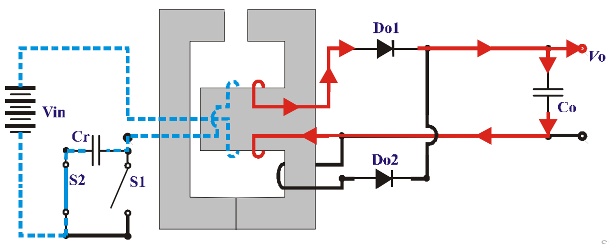


Key Waveforms at stage T0-T1

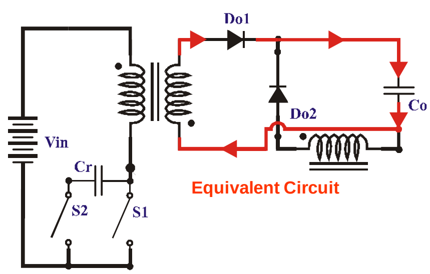


[4]

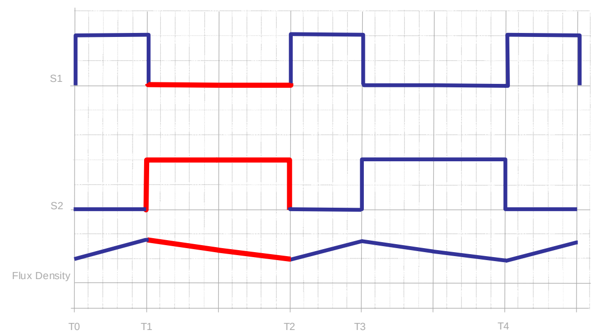
"Current Forced" Flyback with Gapped Magnetic Operation Stage (T1-T2)



(T1-T2)



Key Waveforms at stage T1-T2



[4]

INTEGRATED MAGNETIC

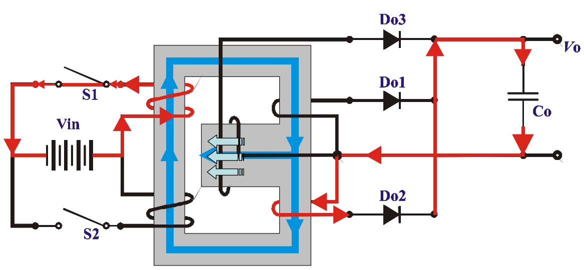
DELTA Energy Systems

OUTLINE

- I.M. Derived from Cielo's Concept
- I.M Derived from Fractional Turns
- I.M. Derived from "8" Shape Winding

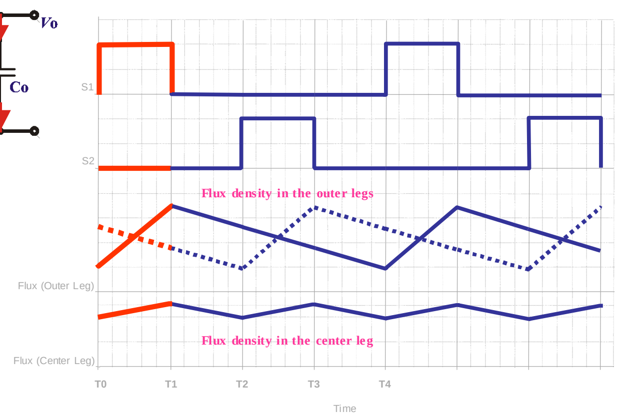
DELTA Energy Systems

Cielo's Push-Pull with I.M. Operation Stage (T0-T1)



(T0-T1)

Key Waveforms at stage T0-T1

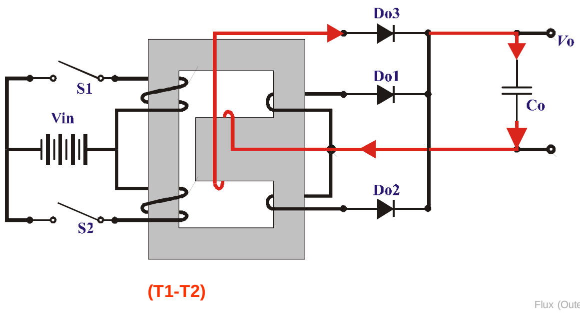


Version 1

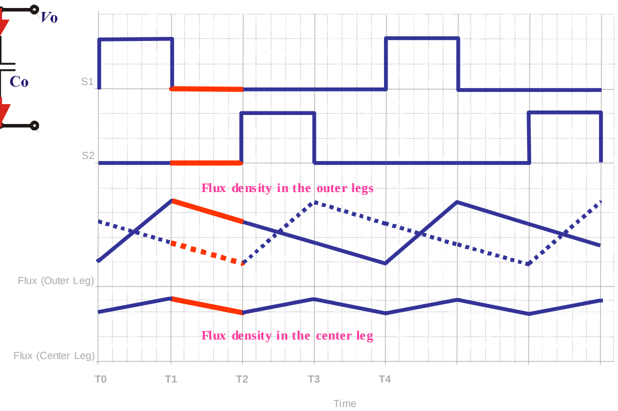
[2]

Delta Energy Systems

Cielo's Push-Pull with I.M. Operation Stage (T1-T2)



Key Waveforms at stage T1-T2

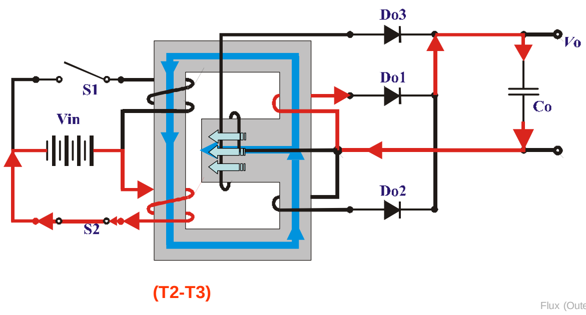


Version 1

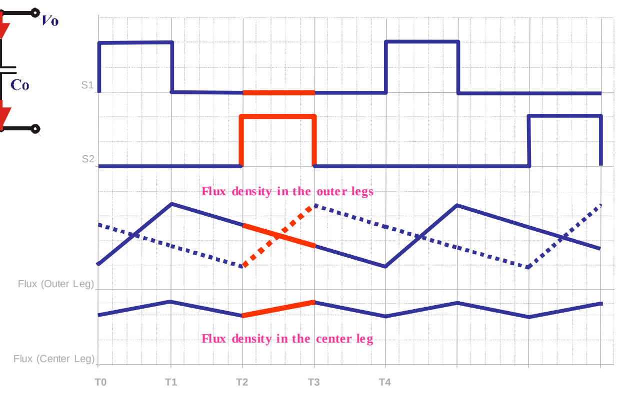
[2]

Delta Energy Systems

Cielo's Push-Pull with I.M. Operation Stage (T2-T3)



Key Waveforms at stage T2-T3

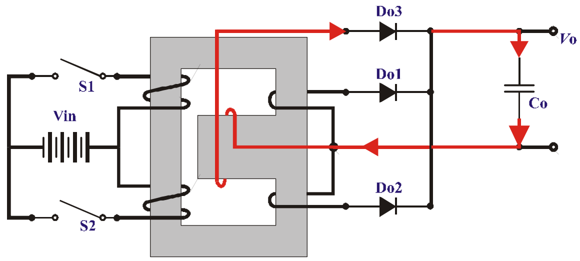


Version 1

[2]

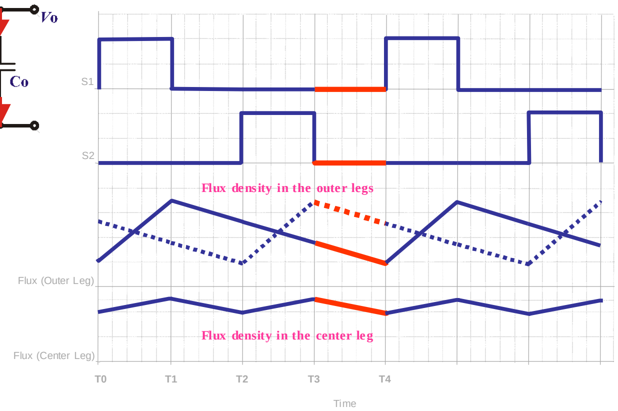
![DELTA Energy Systems]

Cielo's Push-Pull with I.M. Operation Stage (T3-T4)



(T3-T4)

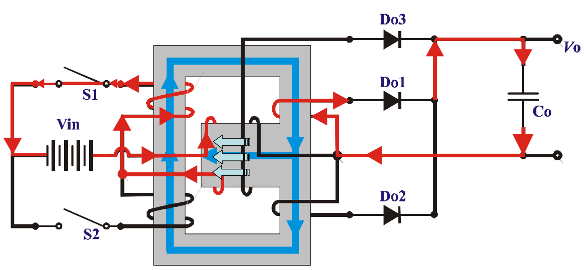
Key Waveforms at stage T3-T4



Version 1

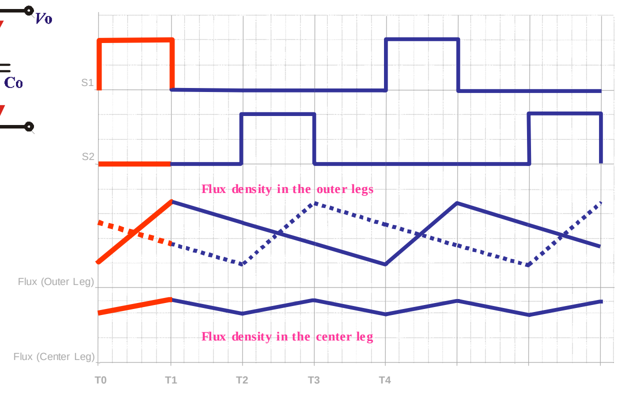
[2]

Cielo's Push-Pull with I.M. Version 2 Stage (T0-T1)



(T0-T1)

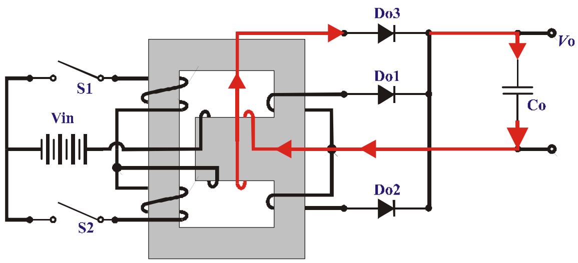
Key Waveforms at stage T0-T1



Version 2

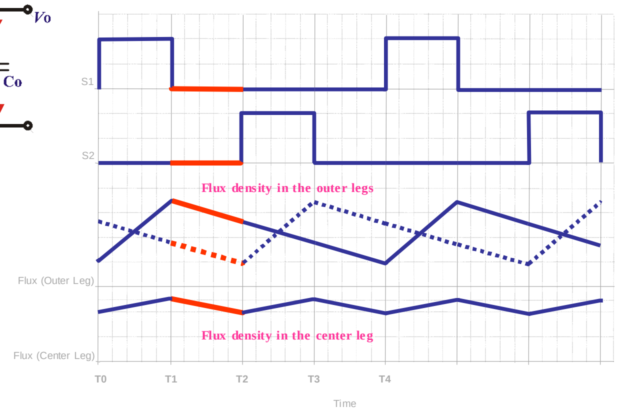
[2]

Cielo's Push-Pull with I.M. Version 2
Stage (T1-T2)



(T1-T2)

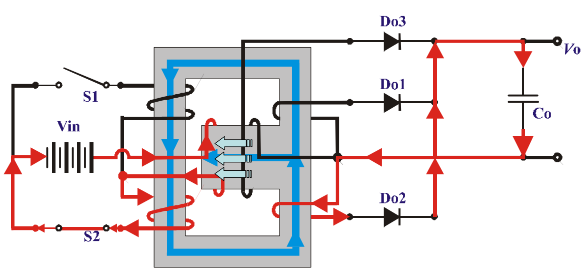
Key Waveforms at stage T1-T2



Version 2

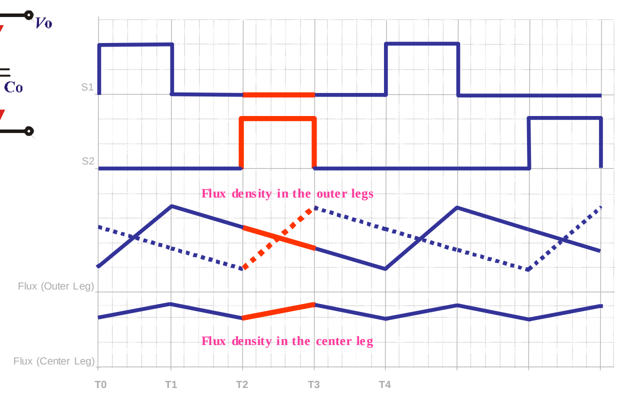
[2]

Cielo's Push-Pull with I.M. Version 2
Stage (T2-T3)



(T2-T3)

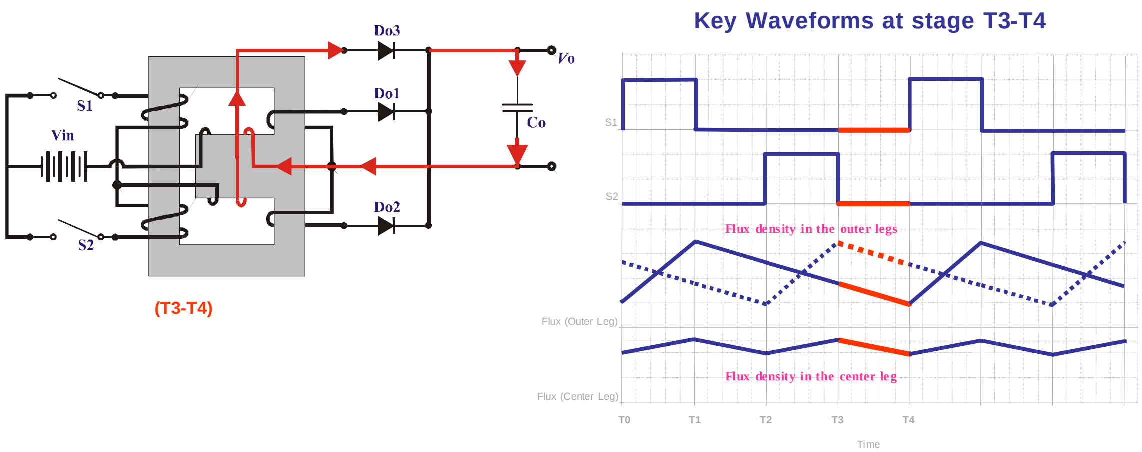
Key Waveforms at stage T2-T3



Version 2

[2]

Cielo's Push-Pull with I.M. Version 2
Stage (T3-T4)



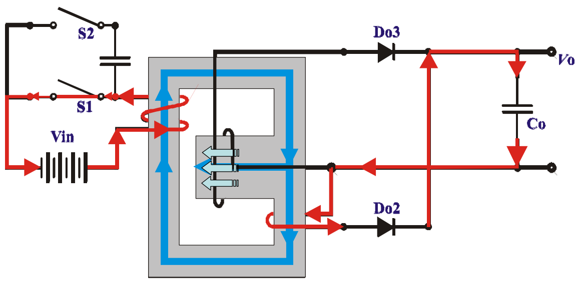
Version 2

[2]

ADVANTAGES OF CIELO'S CONCEPT

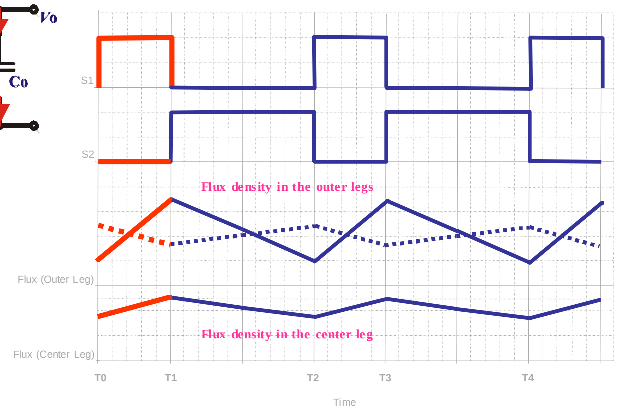
- The gap is placed on the center leg
- The flux density in the center leg has lower ac amplitude and double frequency
- The center leg cross-section can be decreased for copper loss optimization

Single Ended Forward with I.M. Operation
Stage (T0-T1)



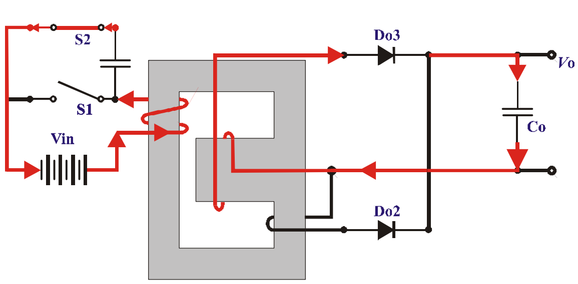
(T0-T1)

Key Waveforms at stage T0-T1



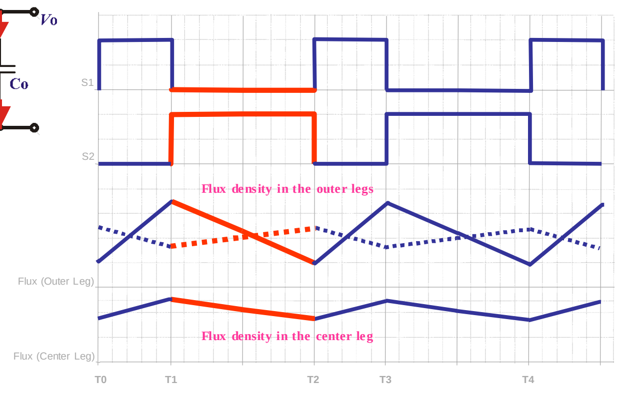
[3]

Single Ended Forward with I.M. Operation
Stage (T1-T2)



(T1-T2)

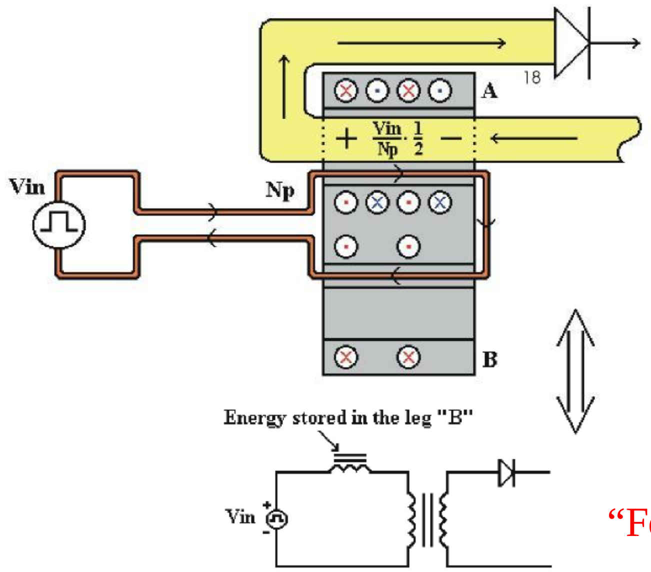
Key Waveforms at stage T1-T2



A simple derivation of Cielo's IM for single ended forward

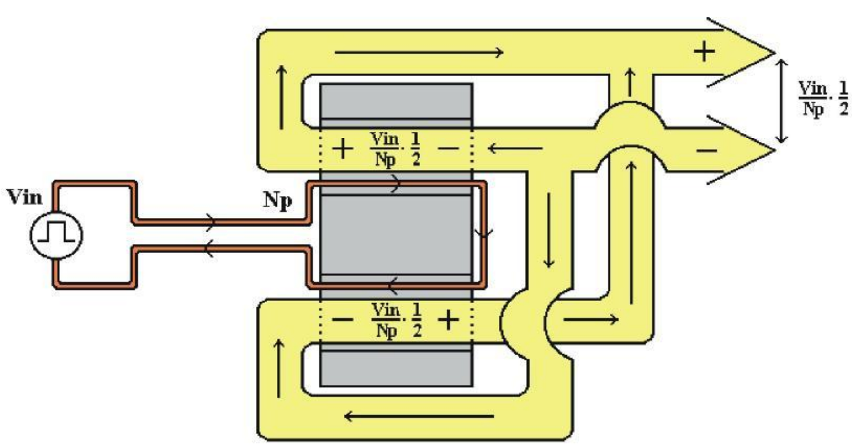
[10]

UNBALANCED FRACTIONAL



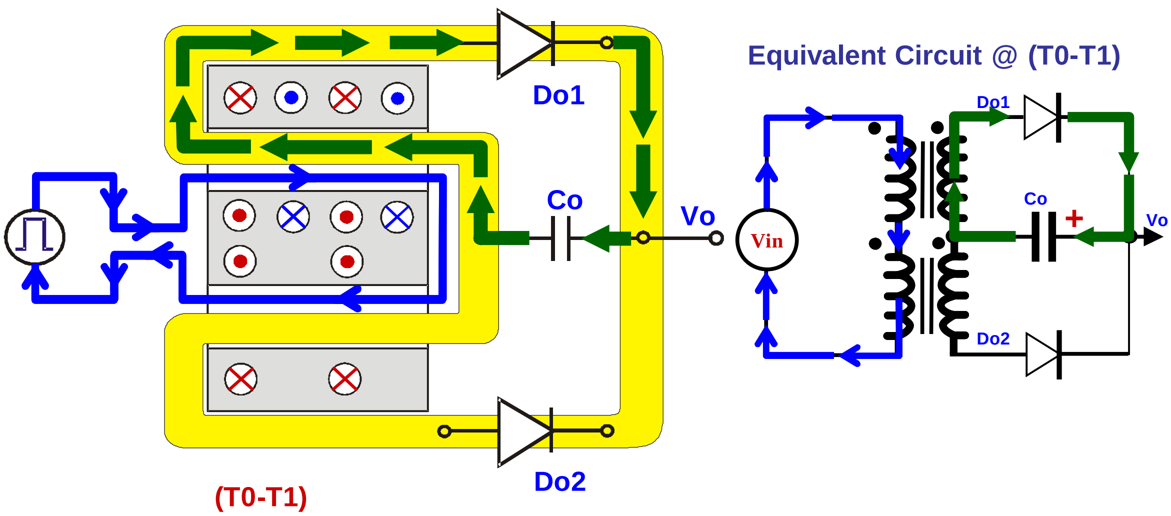
“Foley effect”

TRADITIONAL BALANCED FRACTIONAL TURNS



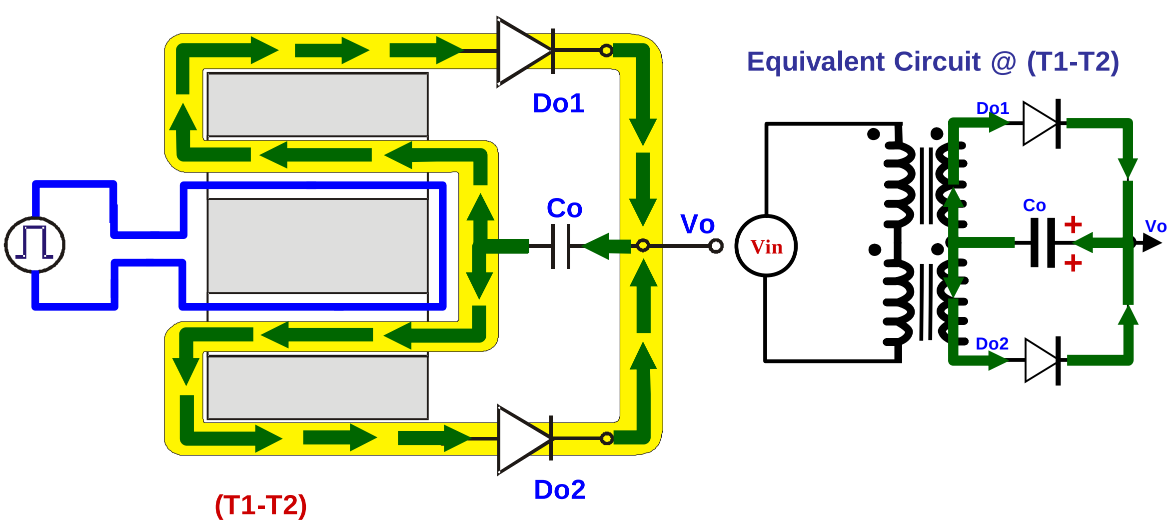
DELTA Energy Systems

INTEGRATED MAGNETICS DERIVED FROM FRACTTIONAL TURNS

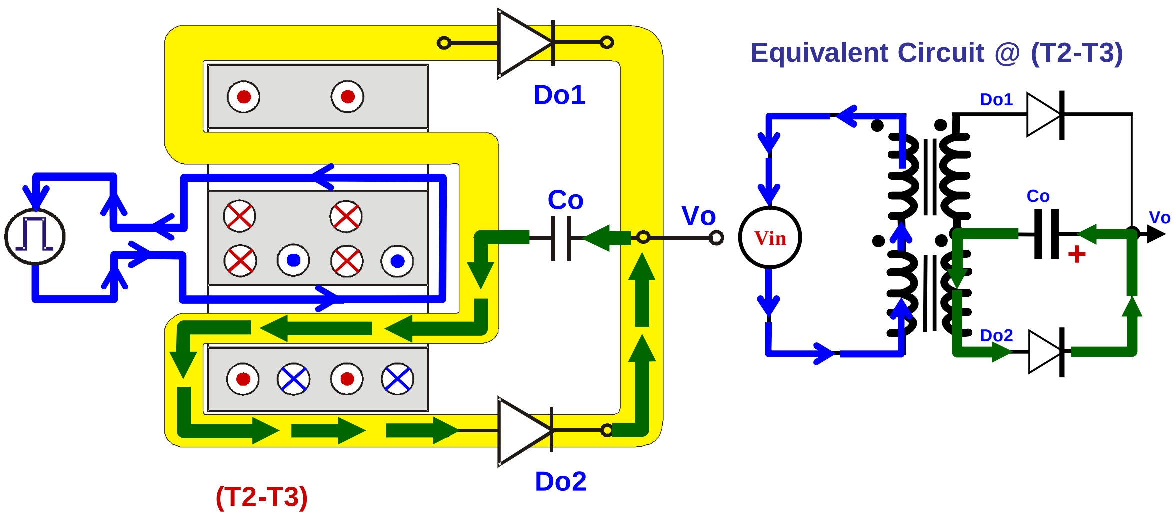


DELTA Energy Systems

INTEGRATED MAGNETICS DERIVED FROM FRACTTIONAL TURNS

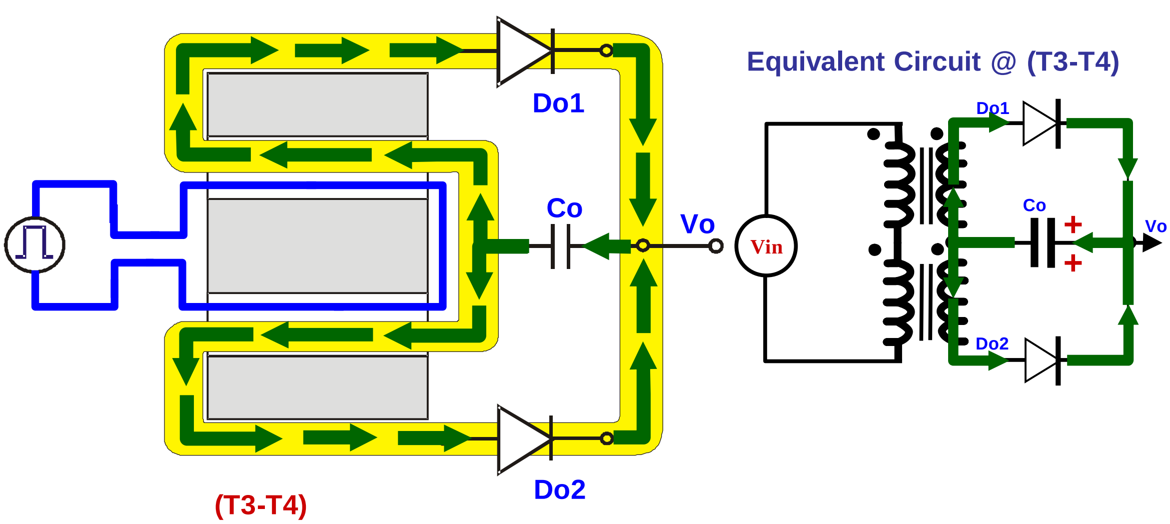


INTEGRATED MAGNETICS DERIVED FROM FRACTTIONAL TURNS



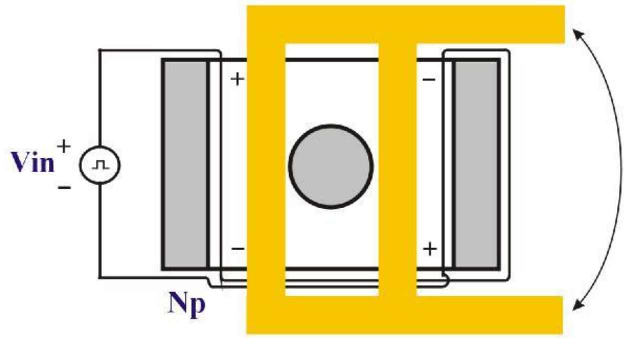
DELTA Energy Systems

INTEGRATED MAGNETICS DERIVED FROM FRACTTIONAL TURNS



Delta Confidential

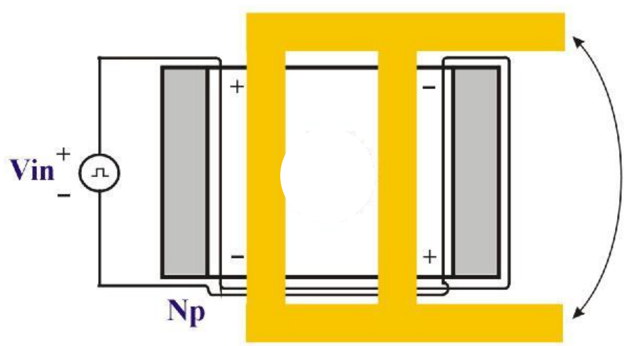
NEW FRACTIONAL TURNS CONCEPT



$$\frac{Vin}{Np} \cdot \frac{1}{2}$$

[5]

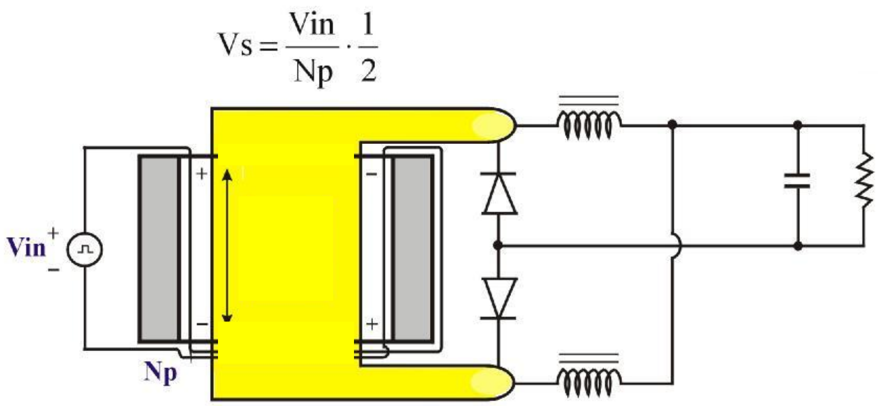
NEW FRACTIONAL TURNS CONCEPT



$$\frac{Vin}{Np} \cdot \frac{1}{2}$$

DELTA Energy Systems

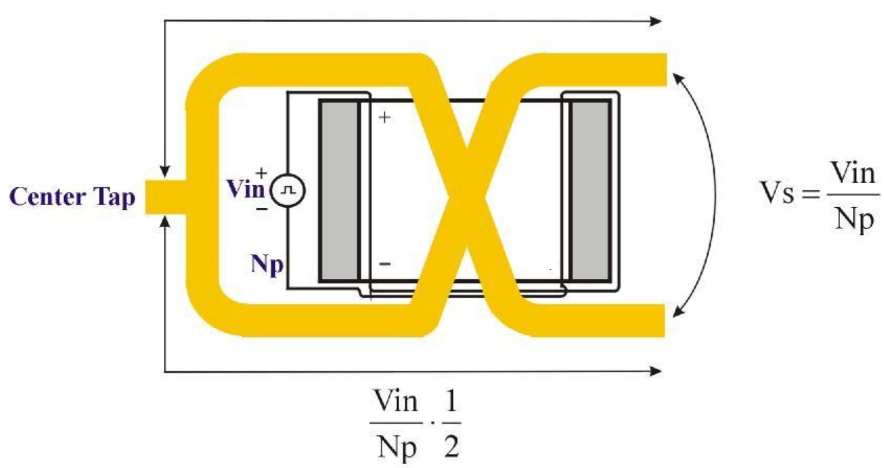
DOUBLE ENDED HALF TURN



[5]

DELTA Energy Systems

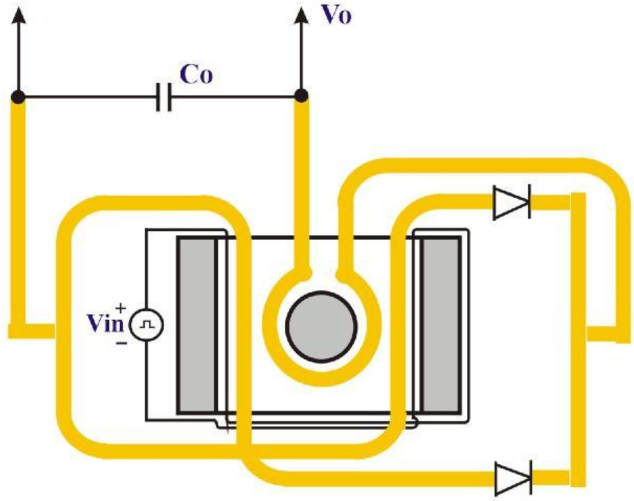
CENTER TAP HALF TURN



[5]

DELTA *Energy Systems*

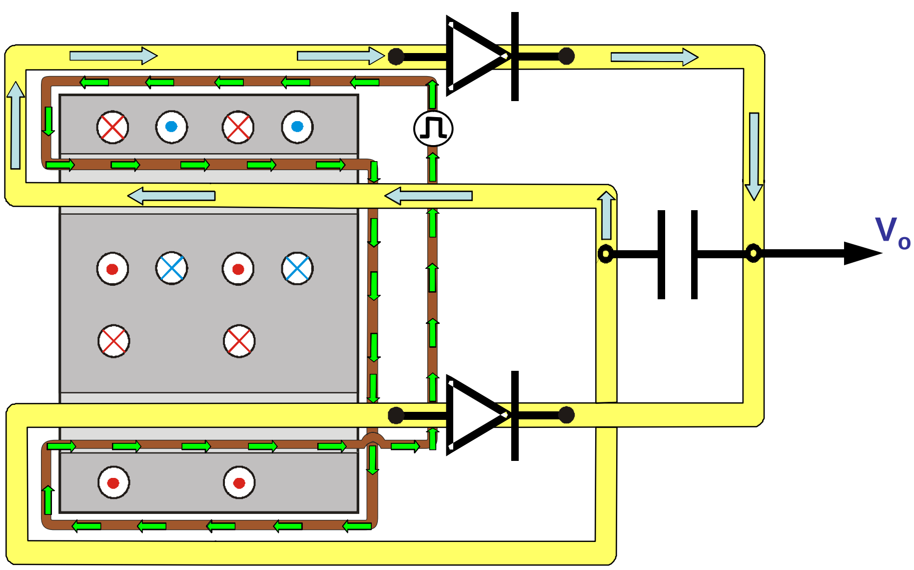
INTEGRATED MAGNETICS DERIVED FROM "8" SHAPE WINDING



[5]

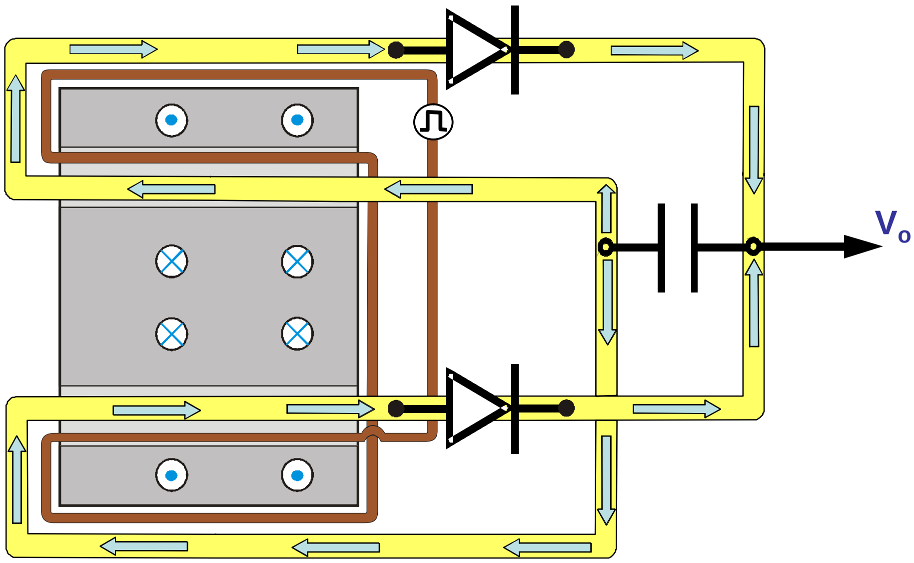
DELTA *Energy Systems*

INTEGRATED MAGNETICS DERIVED FROM "8" SHAPE WINDING



[1],[5]

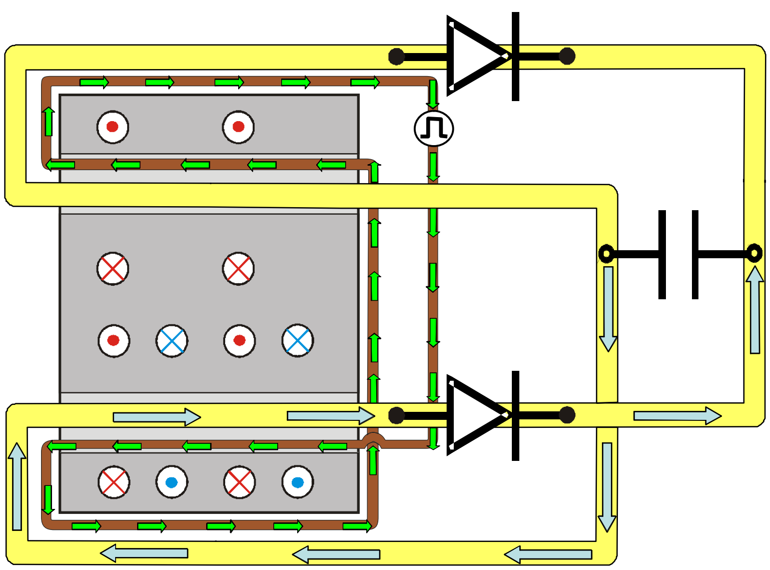
INTEGRATED MAGNETICS DERIVED FROM "8" SHAPE WINDING



[1],[5]

DELTA Energy Systems

INTEGRATED MAGNETICS DERIVED FROM "8" SHAPE WINDING

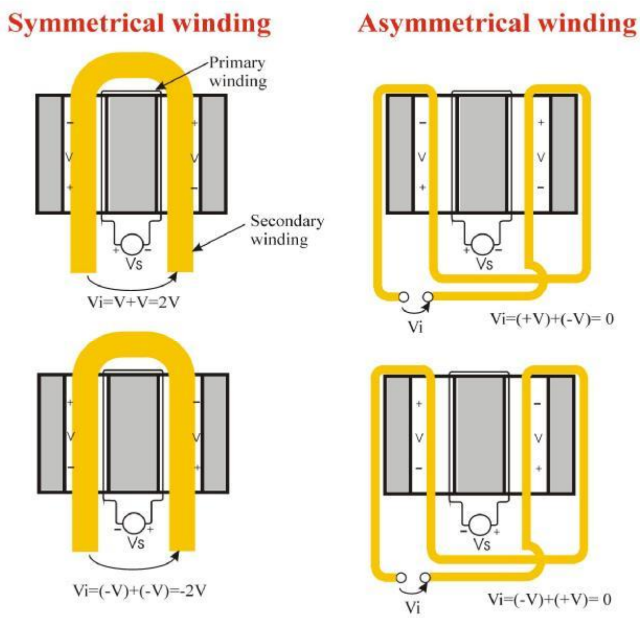


[1],[5]

Delta Confidential

Delta Energy Systems

INTEGRATING SIGNAL AND POWER WITH "8" SHAPE WINDING

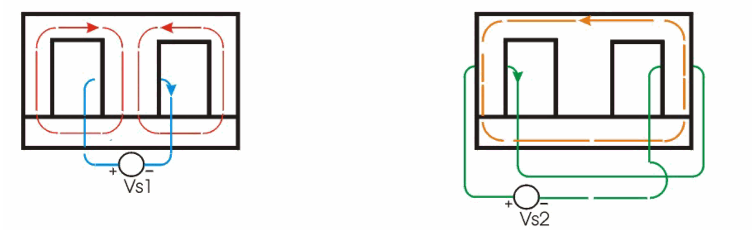


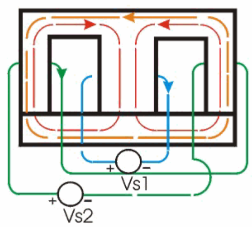
"Signal Transfer through Power"

[9]

Flux induced by a "symmetrical" winding

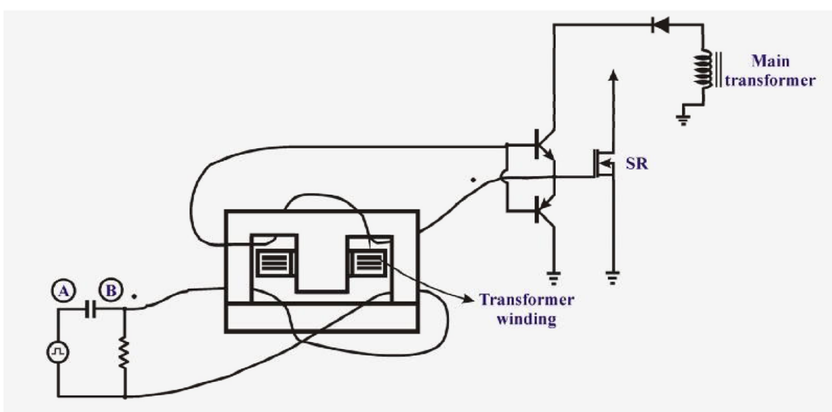
Flux induced by an "asymmetrical" winding

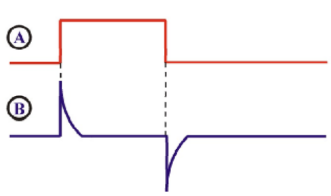




"Signal Transfer through Power Magnetic "

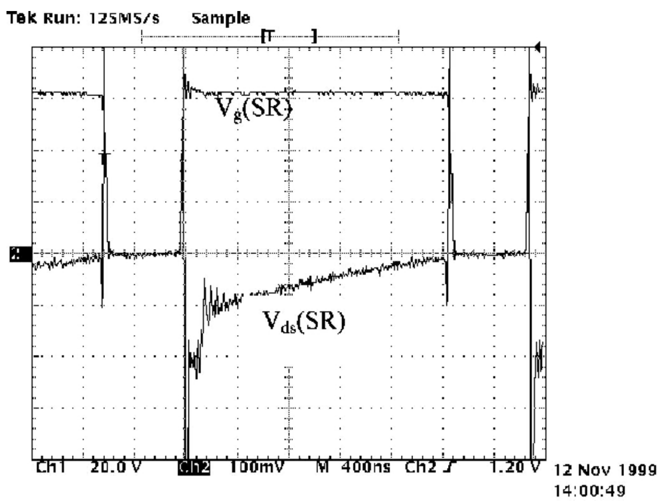
DRIVING CIRCUIT





[9]

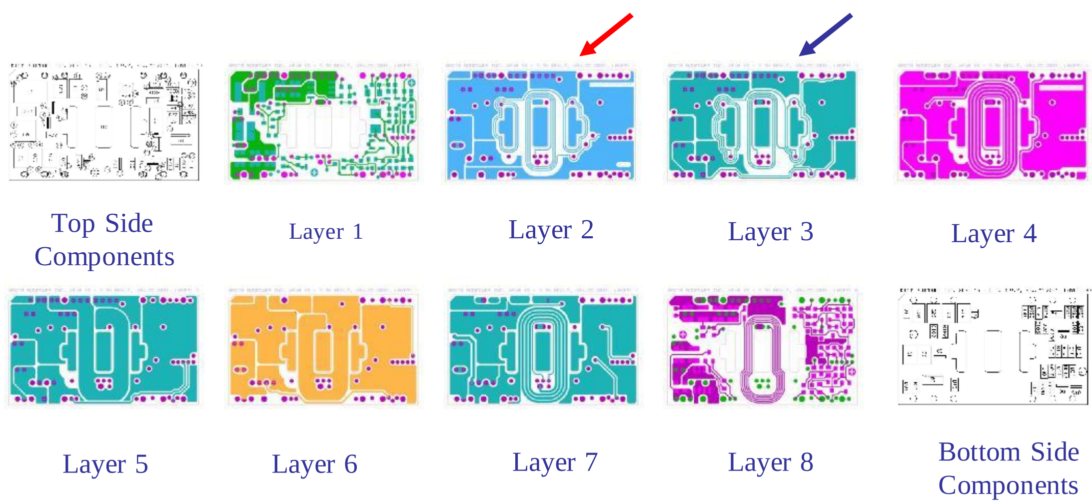
GATE SIGNAL RECONSTRUCTION ON THE SYNCRONOUS RECTIFIER



Vin=32V-75V , Vo=3.3V @ 3A

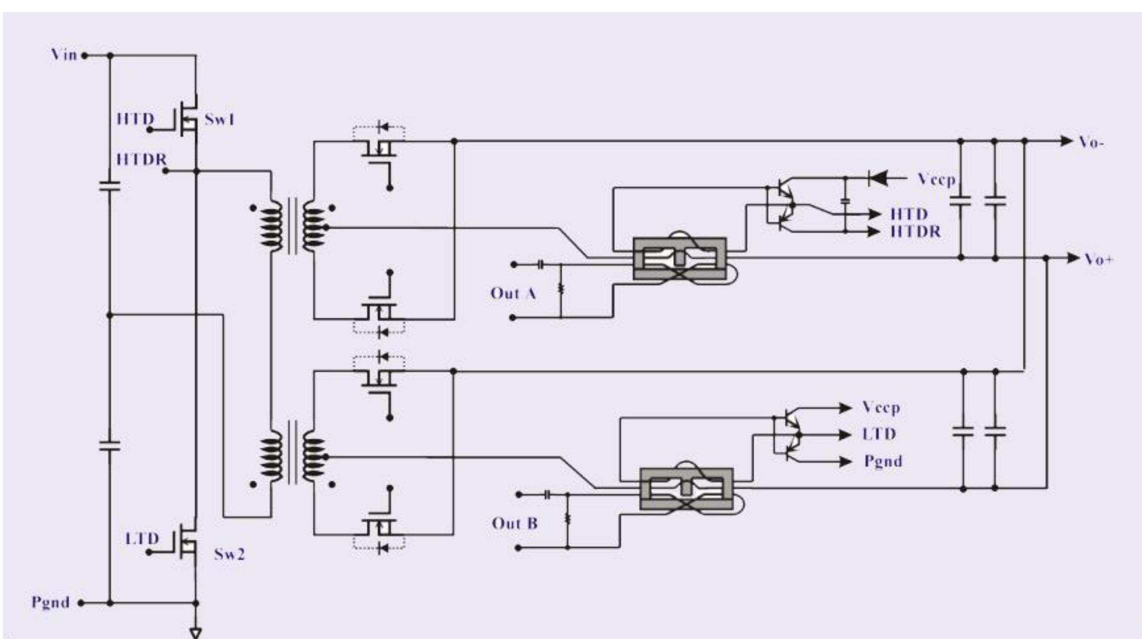
Energy Systems
DUAL FUNCTION MAGNETICS

IMPLEMENTATION OF THE 15W DC-DC CONVERTER WITH SYNCHRONOUS RECTIFICATION



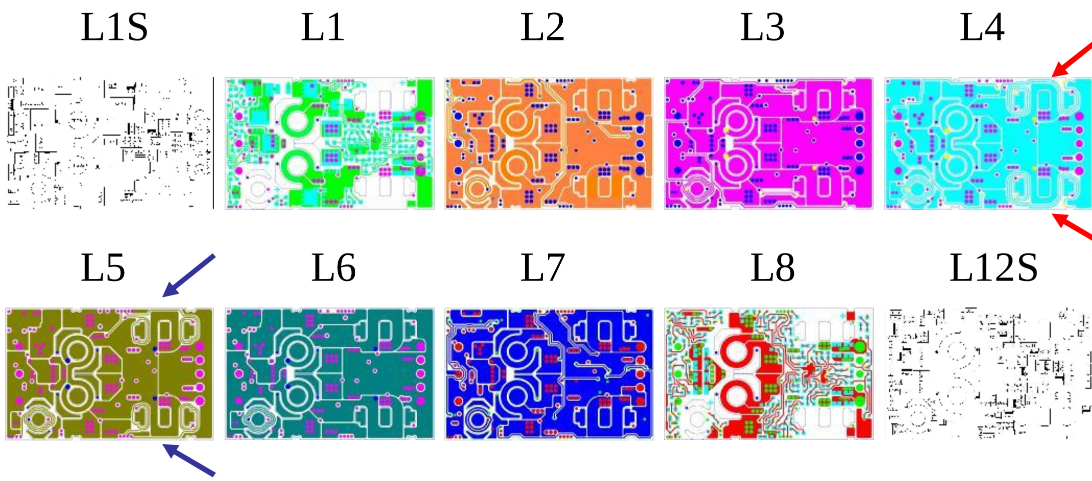
15W DC-DC CONVERTER

DRIVING CIRCUIT

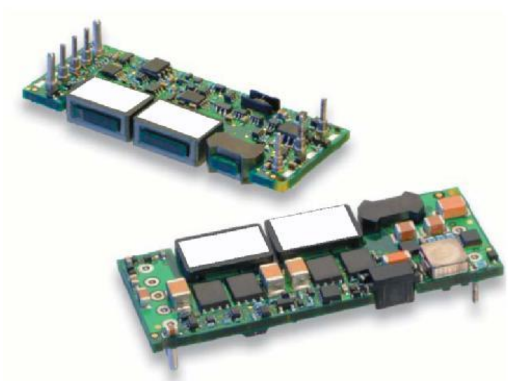


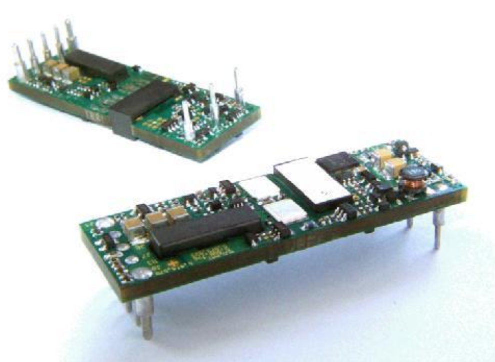
[9]

IMPLEMENTATION OF THE DRIVING



DUAL FUNCTION MAGNETICS



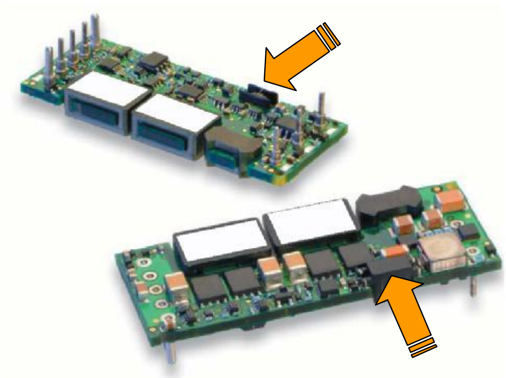


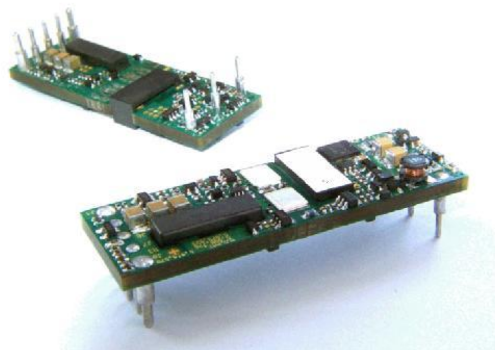
[9]

Delta Confidential

Energy Systems

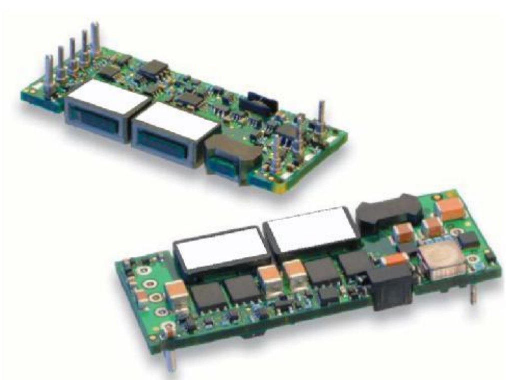
DUAL FUNCTION MAGNETICS

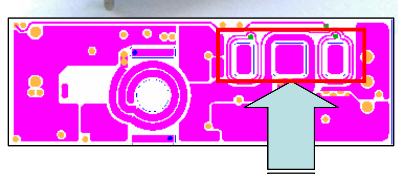




Energy Systems

DUAL FUNCTION MAGNETICS



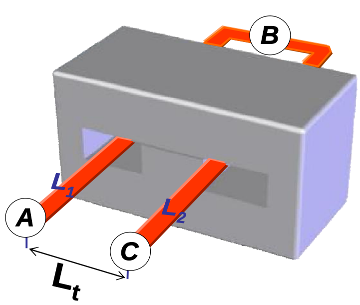


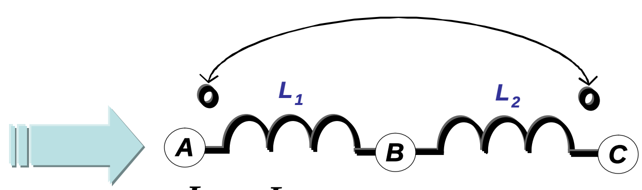
DELTA Energy Systems

KEY FEATURES OF THIS TECHNOLOGY

- Eliminates the need for an additional magnetic element
- Improves the utilization of the power transformer
- Very low delay time in the signal transfer
- <u>Low cost</u> – No additional cost for the signal transformer

DELTA Energy Systems





$$L_t = L_1 = L_2$$

$$L_t = L + L - 2M$$

Where:

$$M = k\sqrt{L_1 L_2}$$

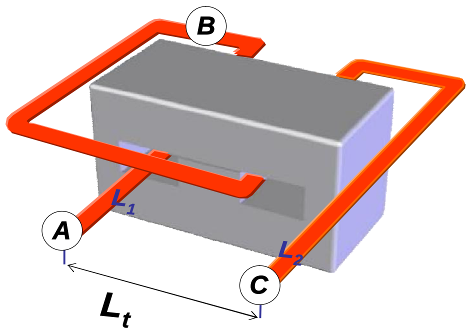
$$L_t = L + L - 2kL$$

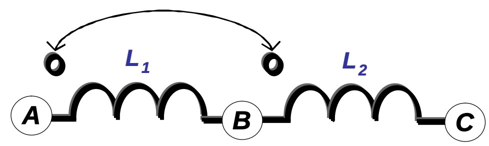
Example:

$k = 1 \Rightarrow L_t = 0$

$k = 0 \Rightarrow L_t = 2L$

[19]





$$L_t = L_1 = L_2$$

$$L_t = L + L + 2M$$

Where:

$$M = k\sqrt{L_1 L_2}$$

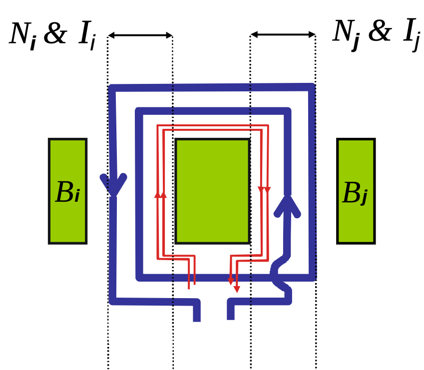
$$L_t = L + L + 2kL$$

Example:

$$k = 1 \Rightarrow L_t = 4L$$

$$k = 0 \Rightarrow L_t = 2L$$

[19]



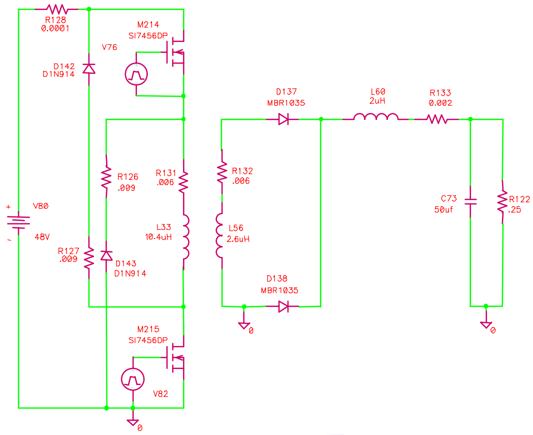
$$B_i = \frac{L_i}{N_i^2 Ae}\left(S\ N_i I_i + kS\ N_j I_j\right)$$

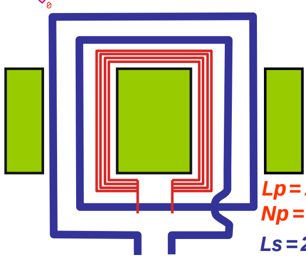
$$B_j = \frac{L_j}{N_j^2 Ae}\left(S\ N_j I_j + kS\ N_i I_i\right)$$

[19]

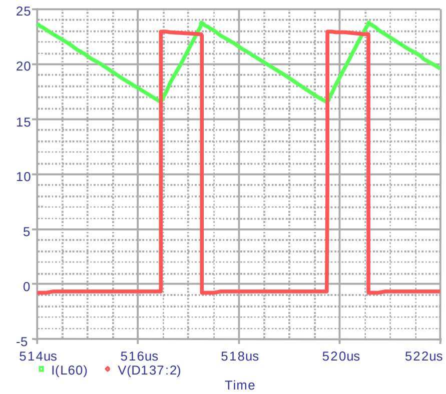
Delta Energy Systems

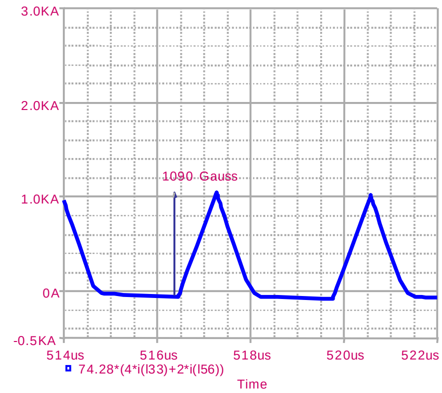
Two Transistor Forward





Lp=10.4mH
Np=4 turns
Ls=2.6mH
Ns=2 turns

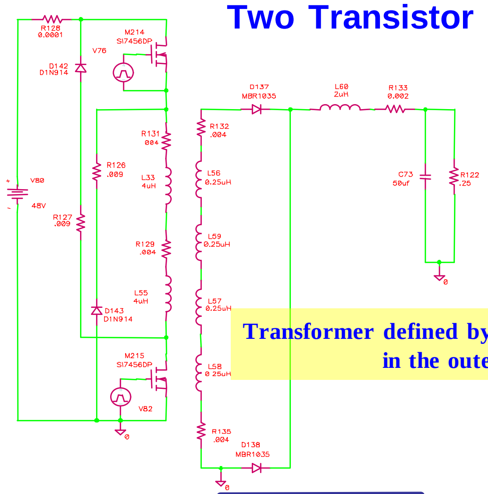




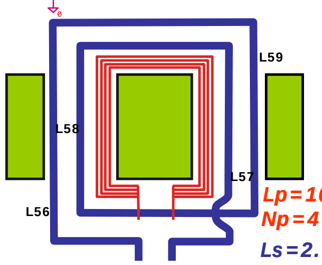
[19]

Delta Energy Systems

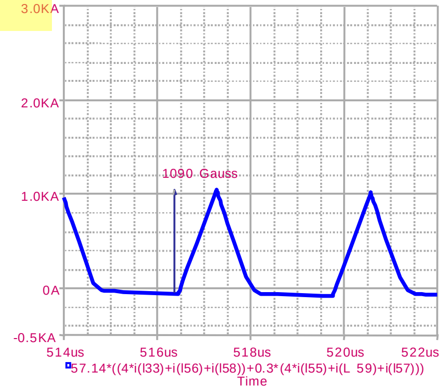
Two Transistor Forward



Transformer defined by two transformers in the outer legs

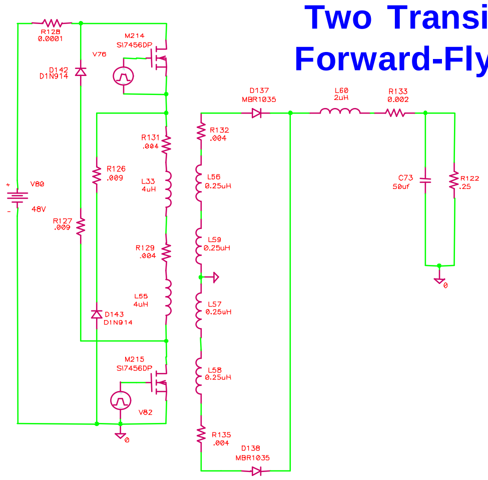


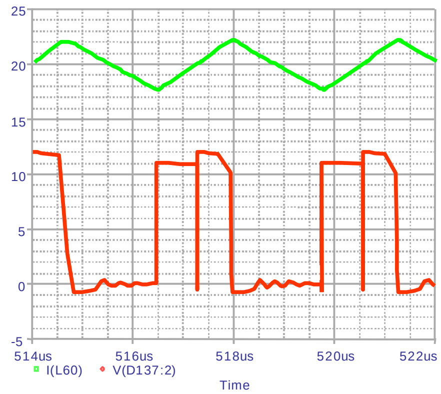
Lp=10.4mH
Np=4 turns
Ls=2.6mH
Ns=2 turns

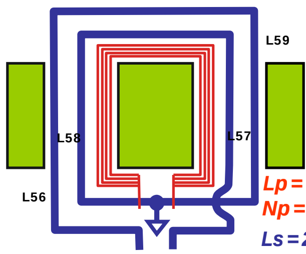


[19]

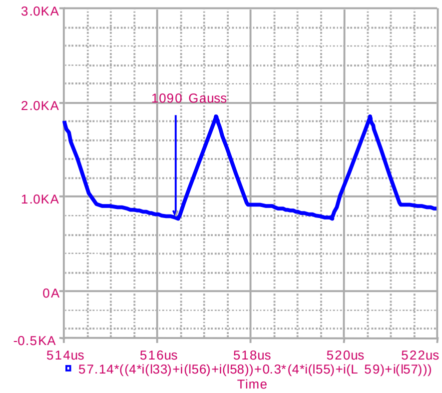
Two Transistor Forward-Flyback





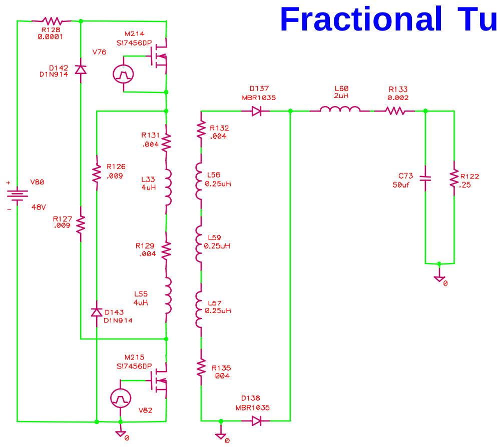


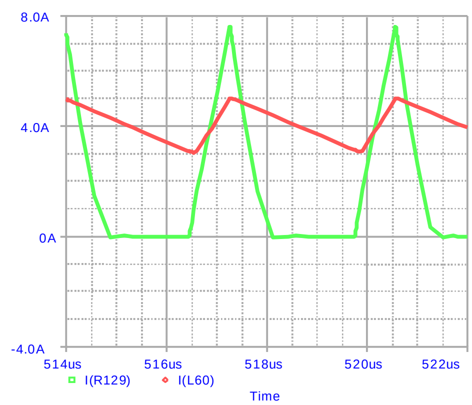
Lp=10.4mH
Np=4 turns
Ls=2.6mH
Ns=2 turns

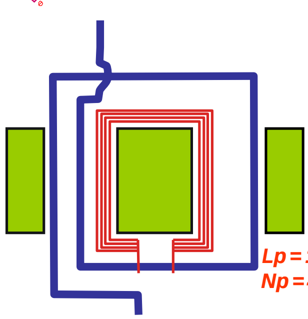


[19]

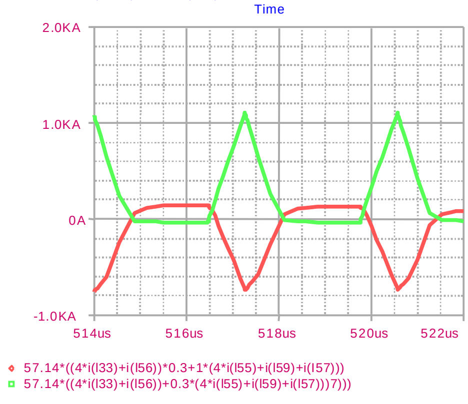
Fractional Turn







Lp=10.4mH
Np=4 turns

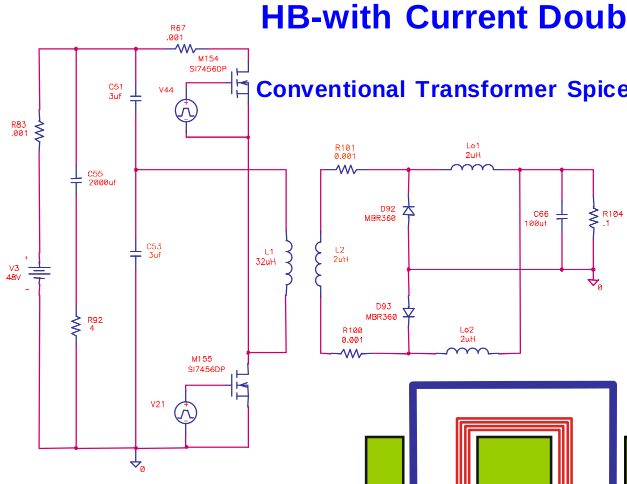


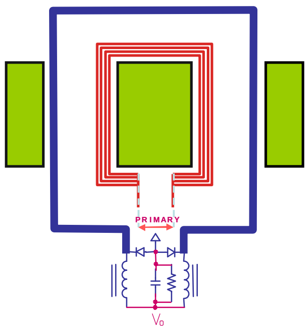
[19]

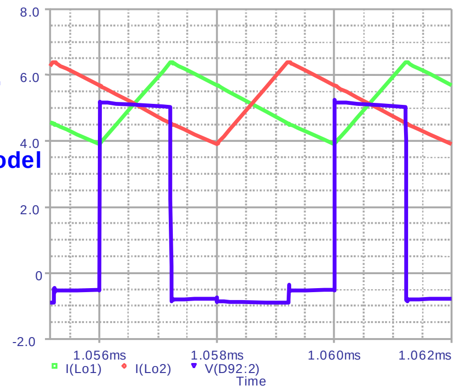
DELTA Energy Systems

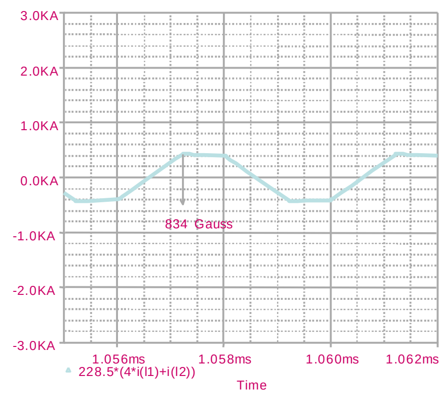
HB-with Current Doubler

Conventional Transformer Spice Model







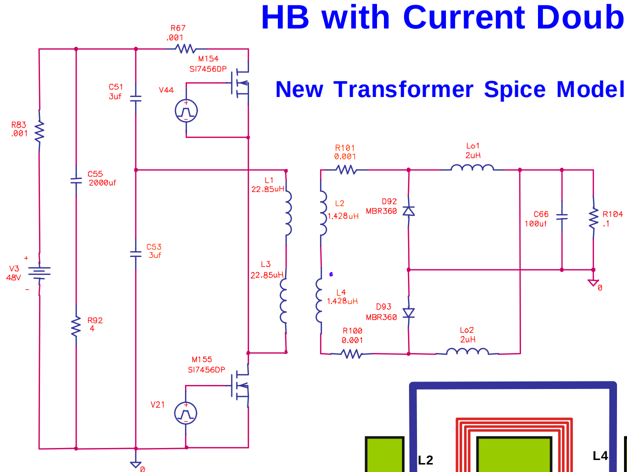


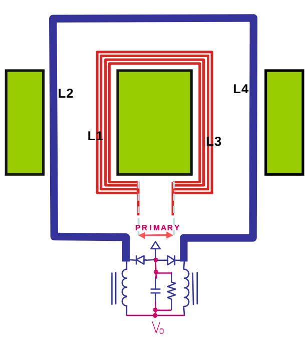
[19]

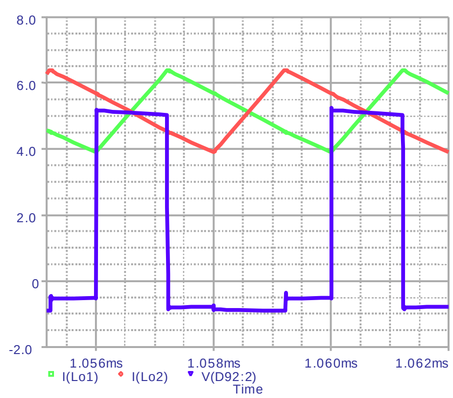
DELTA Energy Systems

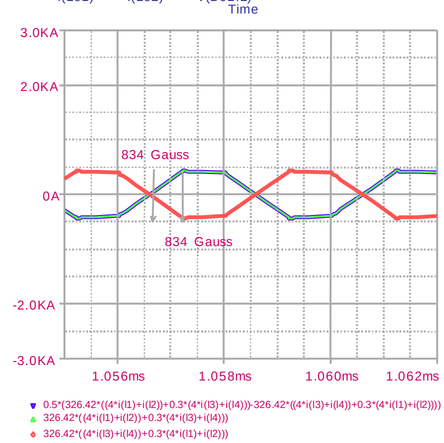
HB with Current Doubler

New Transformer Spice Model



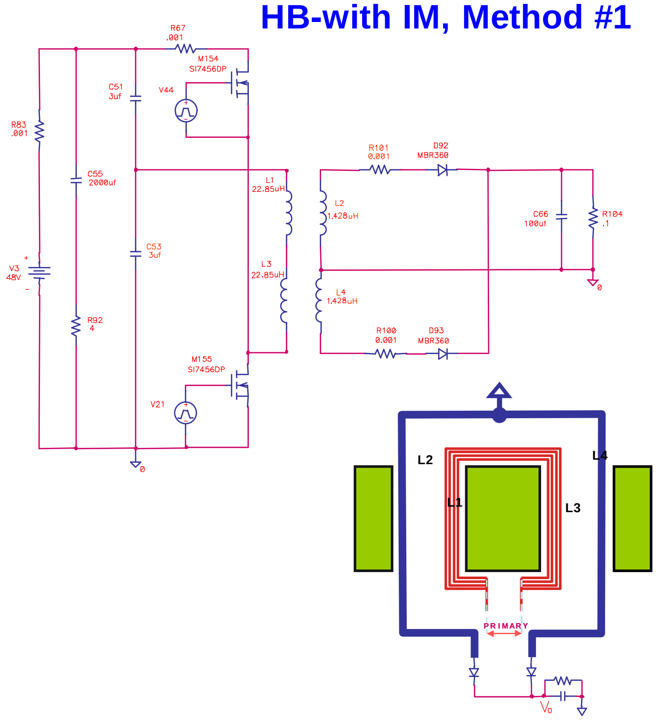






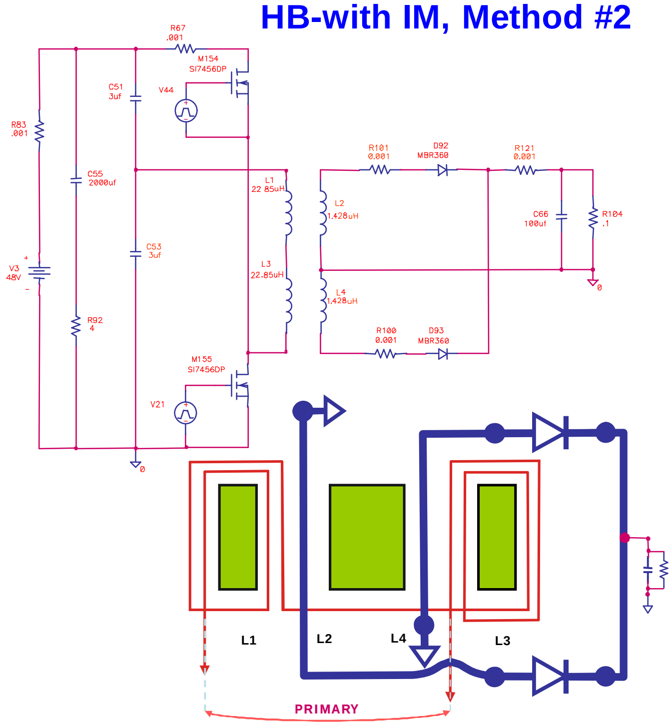
[19]

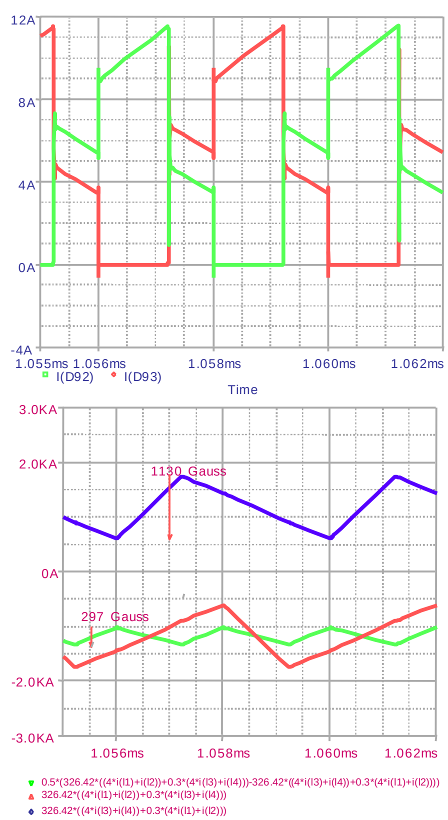
HB-with IM, Method #1



[19]

HB-with IM, Method #2





[19]

Delta Energy Systems

NEW DISTRIBUTED MAGNETIC FOR HIGH EFFICIENCY

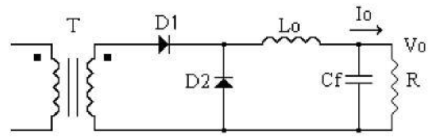
Delta Energy Systems

What is distributed magnetic?

A method to functionally split a larger magnetic element into smaller magnetic elements

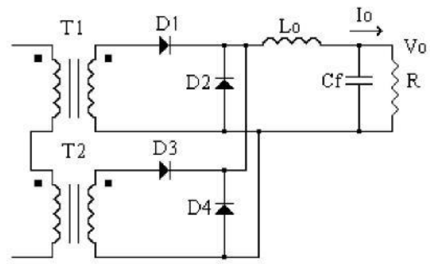
This method interconnects windings of an array of magnetic elements to achieve a certain target, for instance: lower leakage inductance, improved cooling performances, better shock and vibration characteristics

Power train in conventional technology

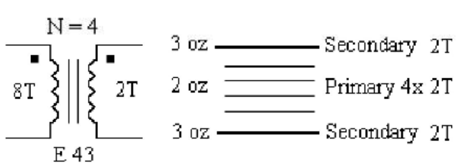


⇓

Power train in distributed magnetic technology

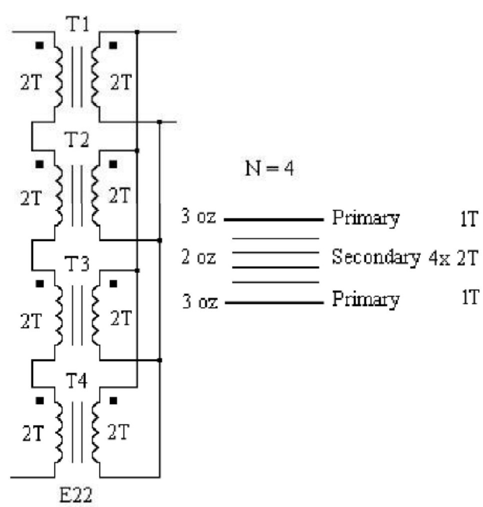


Version 1



E43 - "Centralized magnetic"

Version 2



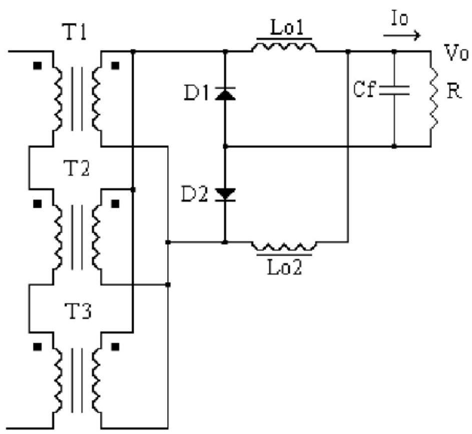
4xE22 - "Distributed magnetic"

Energy Systems

Why distributed magnetics?

- It can offer better performances, electrical, thermal, mechanical
- It is a cost effective method in high power applications
- It is compatible with full integrated multilayer PCB technology

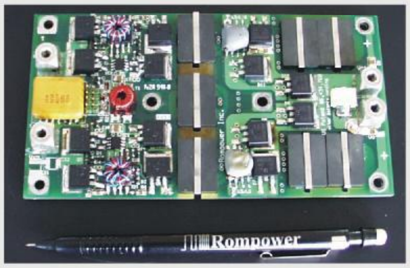
Energy Systems



Distributed transformers and rectifying section for 750W DC-DC Power Module

UNIBODY MAGNETICS-PACKAGING STRUCTURE

- A MERGE BETWEEN MAGNETIC, ELECTRIC AND THERMAL DESIGN



750W DC-DC CONVERTER

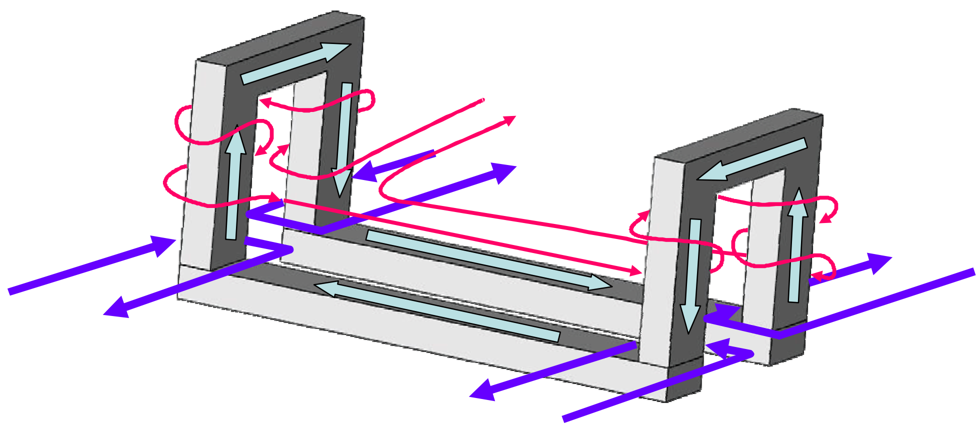
[7],[8], [10]

DISADVANTAGES OF THE DISTRIBUTED MAGNETIC

- Much lower equivalent magnetizing inductance
- Many aspects of it are part of the protected IP, known as “Matrix Transformers”.

ULTRA-PLANAR MAGNETIC

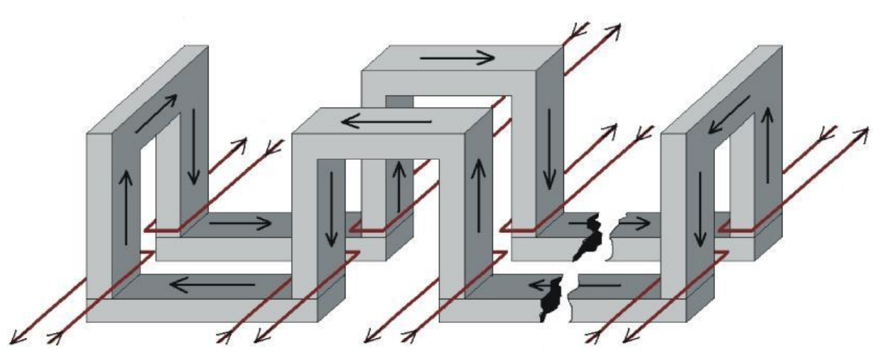
NEW FRACTIONAL TURNS CONCEPT (1/4 TURN)



[16]

ULTRA-PLANAR MAGNETIC

"N" WINDINGS CONCEPT 1/N TURNS

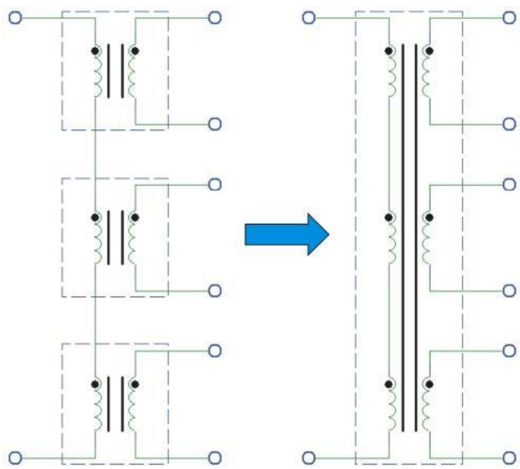


[16]

Energy Systems

ULTRA-PLANAR MAGNETIC

ELECTRICAL EQUIVALENCY

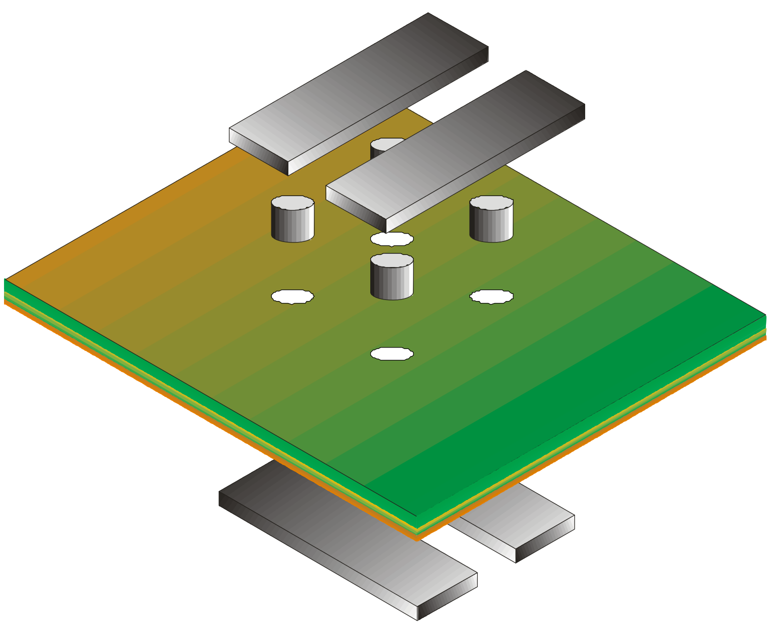


MATRIX TRANSFORMER & THE NEW DISTRIBUTED MAGNETIC

[16]

Energy Systems

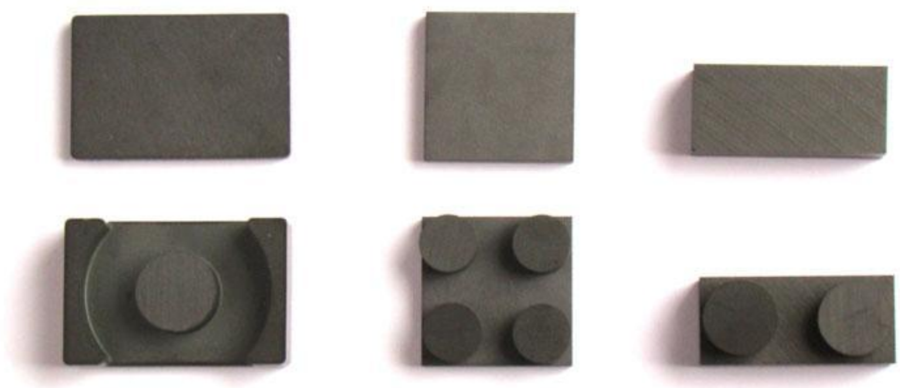
ULTRA-PLANAR MAGNETIC



NEW DISTRIBUTED MAGNETIC

[16], [10]

MAGNETIC STRUCTURE IMPACT ON THE LEAKAGE INDUCTANCE



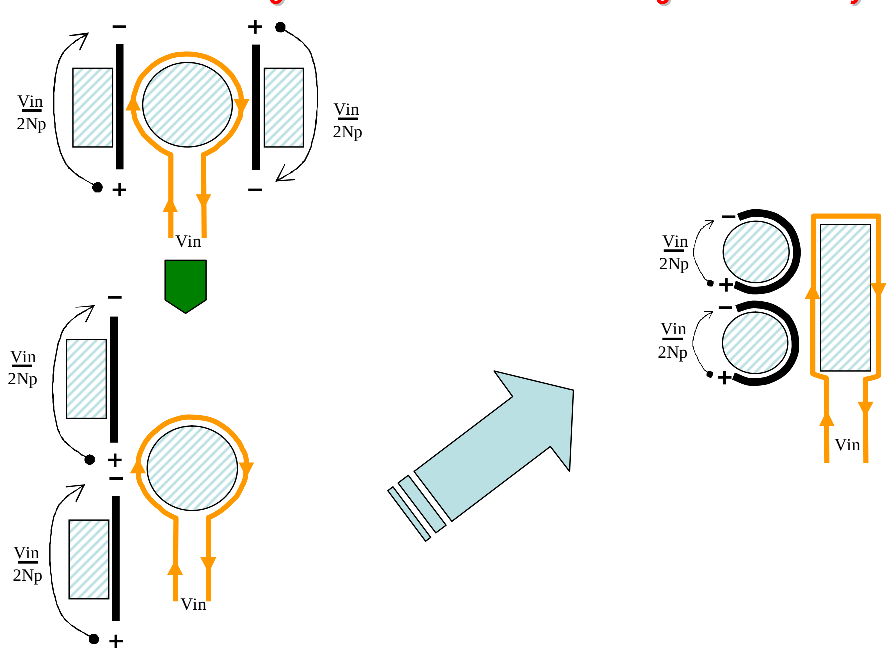
$L_{lek}=K \cdot N^2$

EQ30	4-legged Transformer	2-legged Transformer
$K=4.86 \cdot 10^{-3}$	$K=2.12 \cdot 10^{-3}$	$K=3.08 \cdot 10^{-3}$

[18],[16]

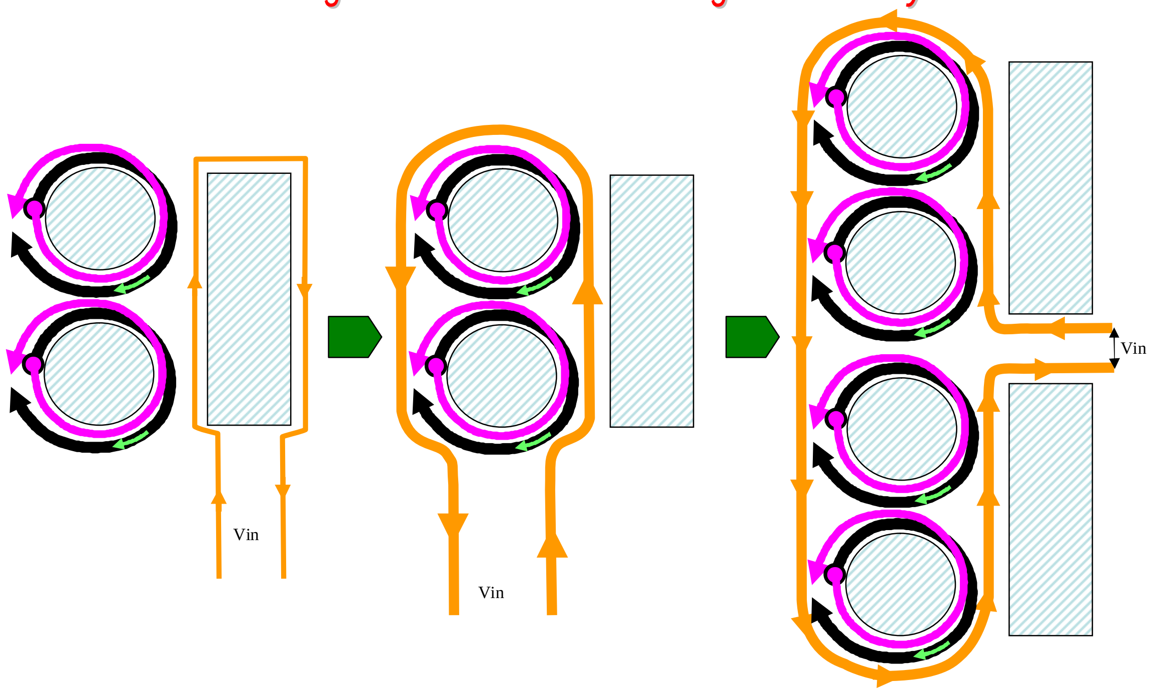
DELTA Energy Systems

Magnetic Structures for High Efficiency



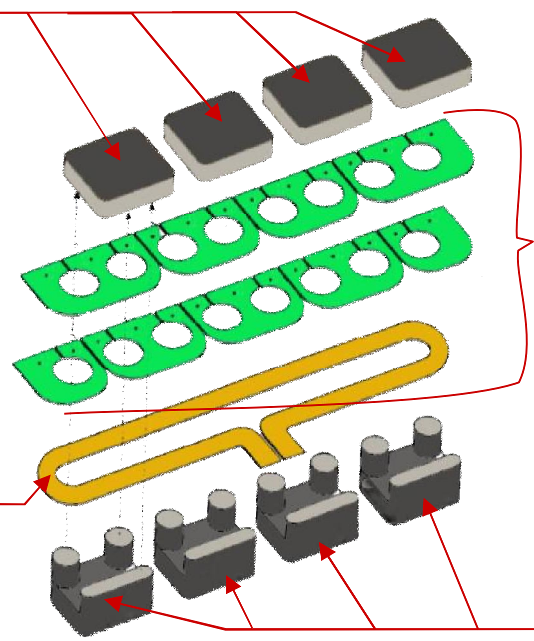
DELTA Energy Systems

Magnetic Structures for High Efficiency



DELTA Energy Systems

Printed Circuit Transformer



[14]

Delta Energy Systems

EXAMPLE OF MAGNETIC OPTIMIZATION

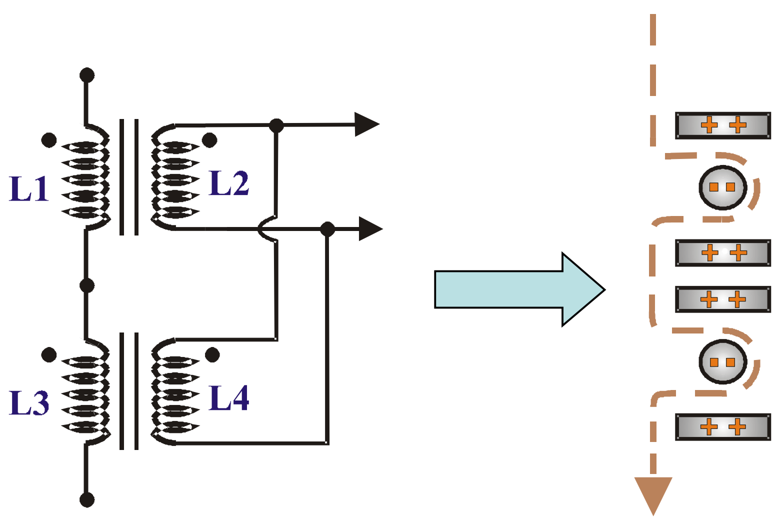
Delta Energy Systems

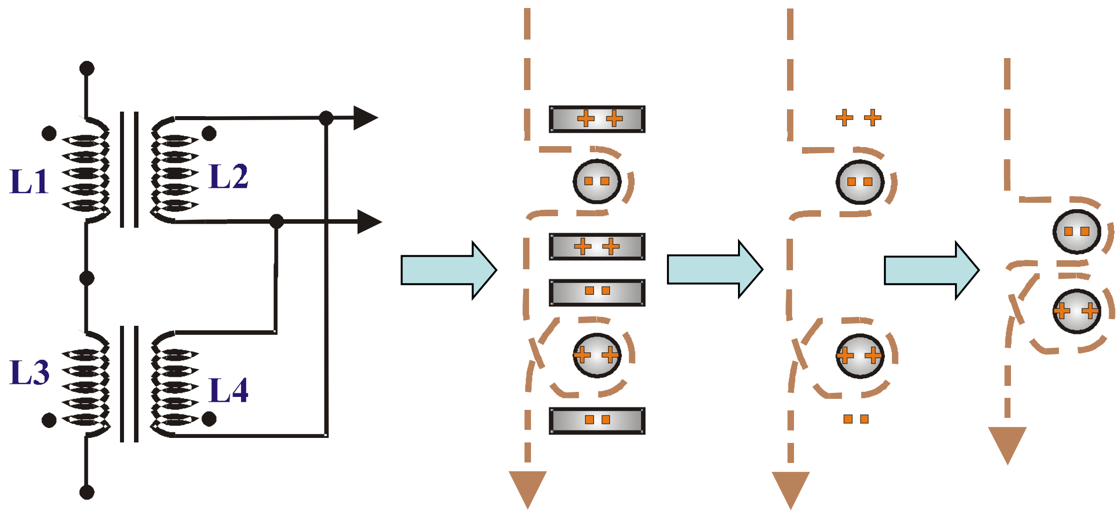
TASK:

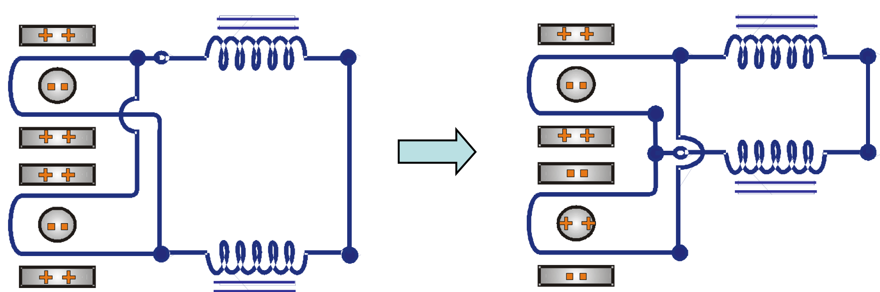
A VERY HIGH CURRENT & LOW VOLTAGE DC-DC CONVERTER **Ex. 1.2V @ 100A**

- **The impact of the leakage and stray inductance**
- **Optimizing the magnetic for high current application**

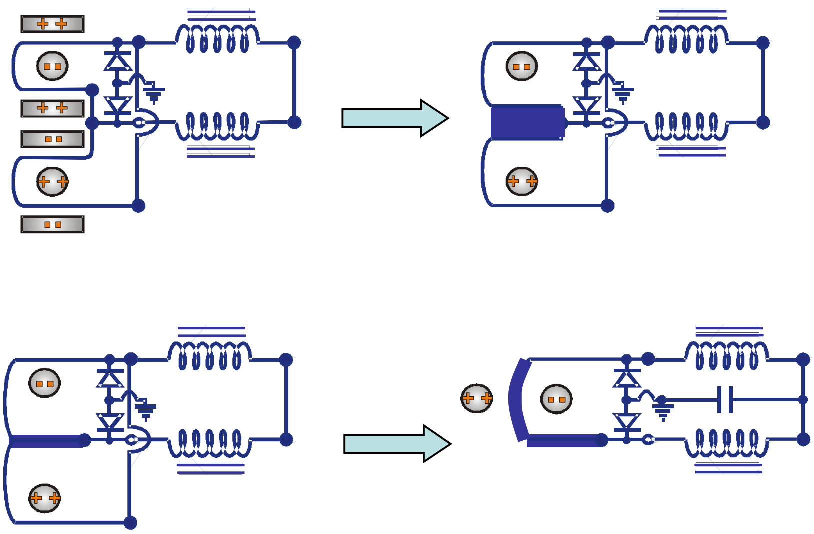
MAGNETIC OPTIMIZATION

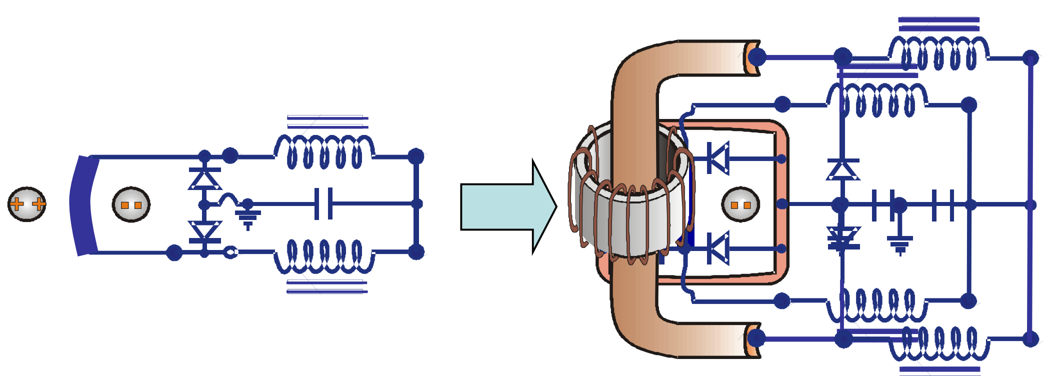


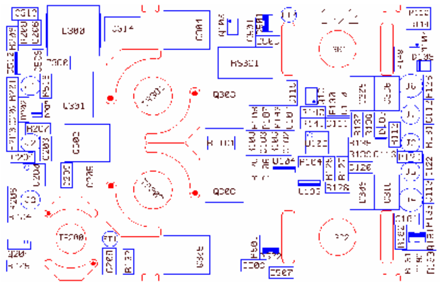


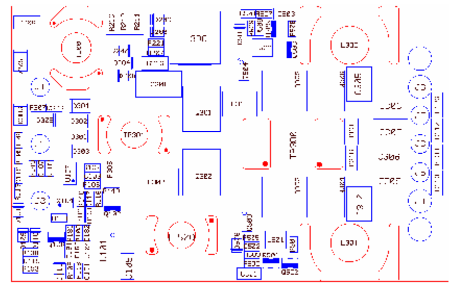


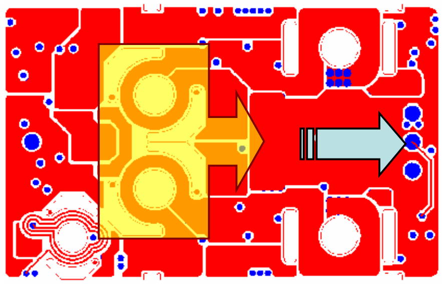
[11],[12]

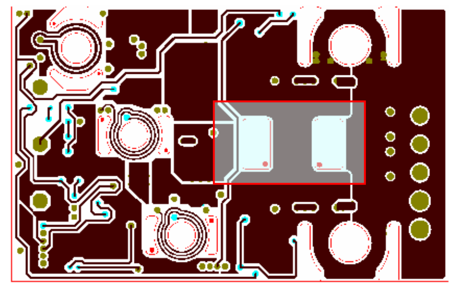


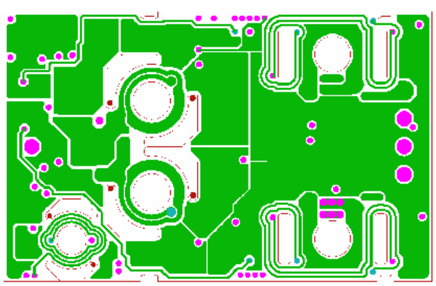


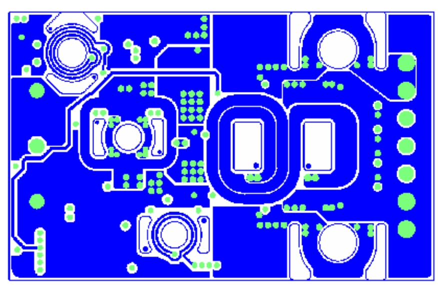


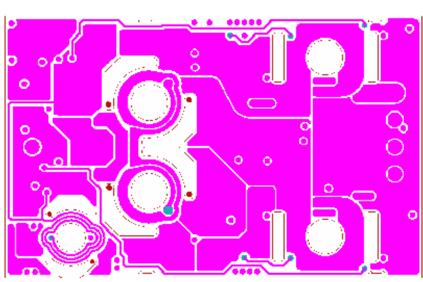


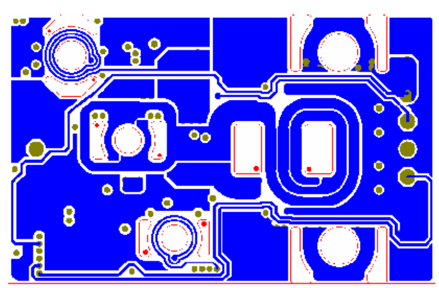


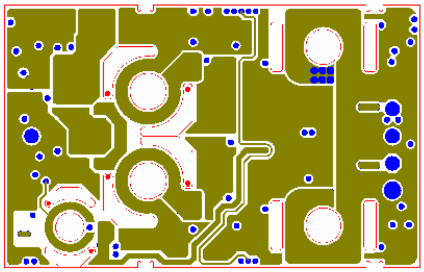


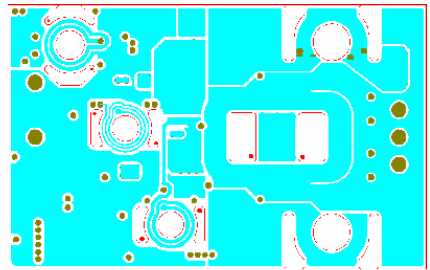




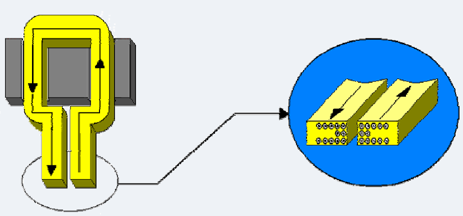


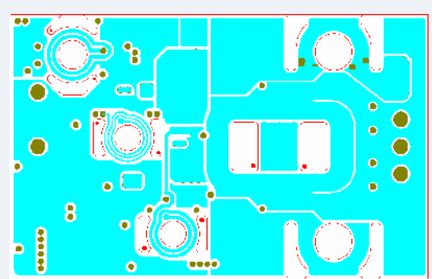


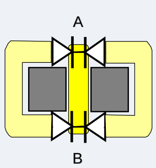


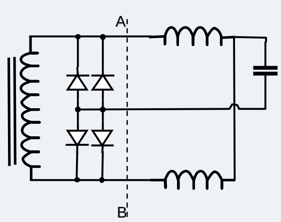


Winding Termination Effects



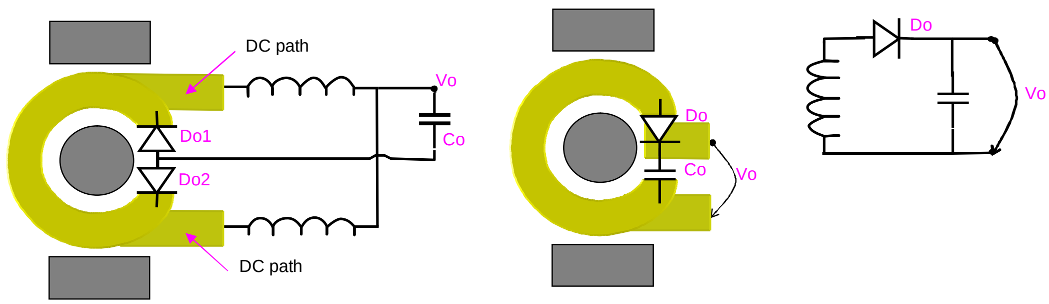






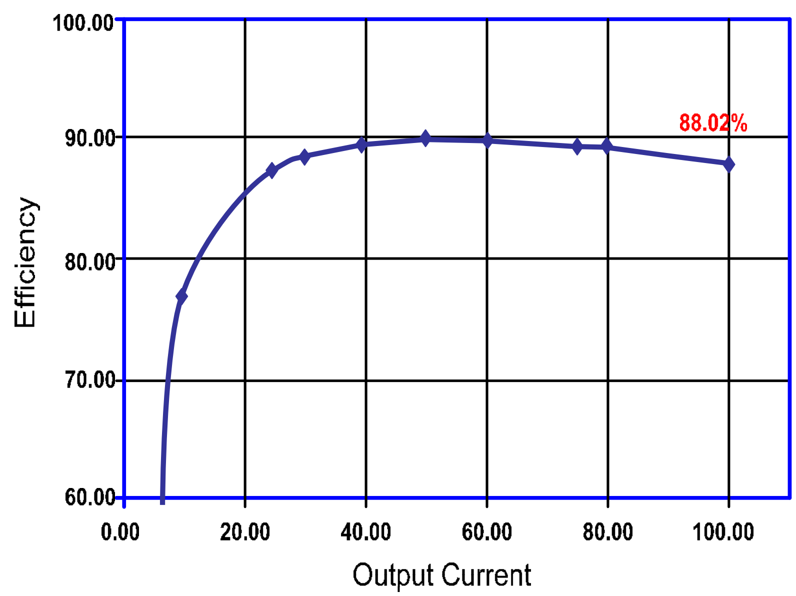
Delta Energy Systems

Winding Termination Effects



Delta Energy Systems

Efficiency Test Result @ Nominal



1V2/100A HC_QB

[7],[8]

CONCLUSION

"MAGNETIC AND LAYOUT OPTIMIZATION A KEY ELEMENT IN BOOSTING THE EFFICIENCY FOR LOW VOLTAGE AND HIGH CURRENT APPLICATION"

Delta Energy Systems

OTHER EXAMPLE OF MAGNETIC OPTIMIZATION

- Copper Loss Optimization through Topology Selection
- Copper Loss Optimization through Magnetic Technology

Delta Energy Systems

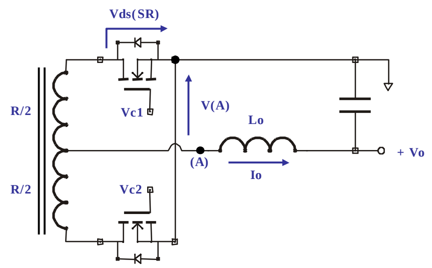
Limitations of the Multilayer PCB Technology

- Limited copper availability
- It is not suitable for large number of turns
- Limited plating capability

DELTA Energy Systems

Rectification Method

Initial Conditions: 4 Layers PCB allocation for secondary
R= DC Impedance for 1 turn



$$P_{d(sec)} = R\,Io^2\left[D + \frac{(1-2D)}{4}\right]$$

$$V_{(A)} = \frac{Vo}{2D}$$

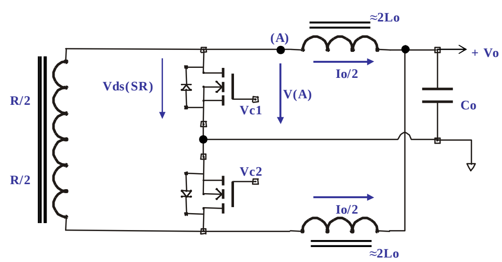
$$V_{ds(SR)} = \frac{Vo}{D}$$

Center-Tapped Configuration

DELTA Energy Systems

Rectification Method

Initial Conditions: 4 Layers PCB allocation for secondary
R=DC Impedance for 1 turn



$$P_{d(sec)} = R\,Io^2\left(\frac{D}{2}\right)$$

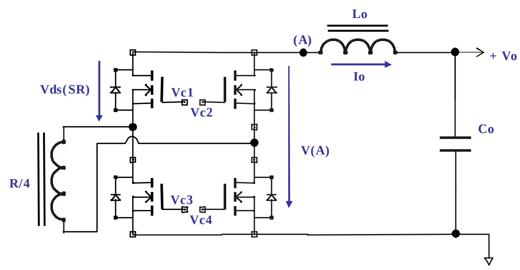
$$V_{(A)} = \frac{Vo}{D}$$

$$V_{ds(SR)} = \frac{Vo}{D}$$

Current-Doubler Configuration

Rectification Method

Initial Conditions: 4- Layers PCB allocation for secondary
R- DC Impedance for 1 turn



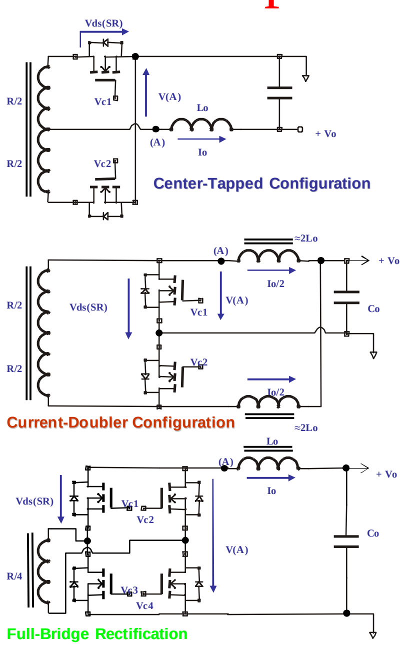
$$P_{d(sec)} = R\, I_o^2 \left(\frac{D}{2}\right)$$

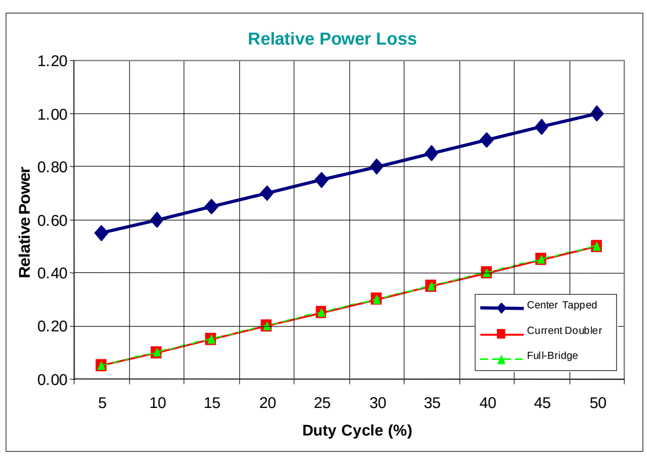
$$V_{(A)} = \frac{Vo}{2D}$$

$$V_{ds(SR)} = \frac{Vo}{2D}$$

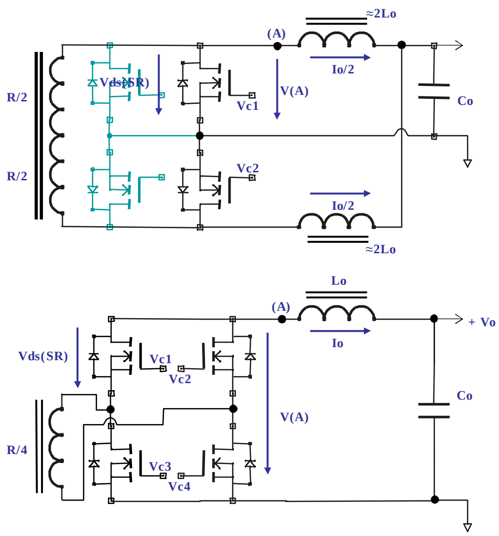
Full-Bridge Rectification

Power Dissipation In The Secondary Winding





Current-Doubler vs Full-Bridge Rectification



$$V_{(A)} = \frac{Vo}{D}$$

$$V_{ds(SR)} = \frac{Vo}{D}$$

For IRF6648 60V @ 5.3mΩ

$$P_d(SR)_{CD} = Io^2\left(D + \frac{1-2D}{4}\right)\left(\frac{5.3mW}{2}\right)2$$

$$V_{(A)} = \frac{Vo}{2D}$$

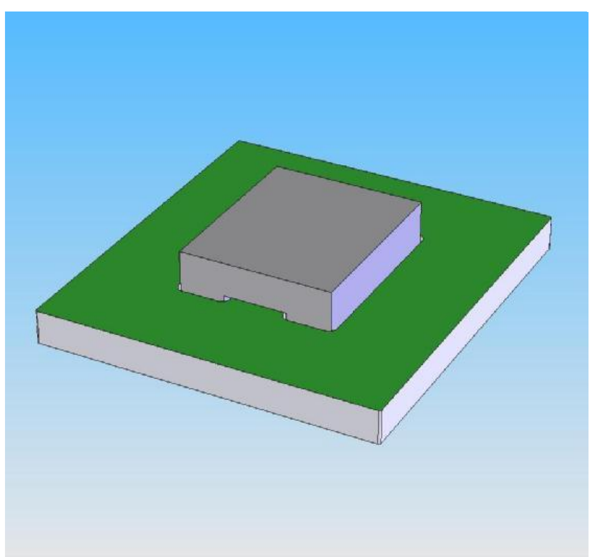
$$V_{ds(SR)} = \frac{Vo}{2D}$$

For IRF6635 30V @ 1.2mΩ

$$P_d(SR)_{FB} = Io^2\left(D + \frac{1-2D}{4}\right)(1.2mW)4$$

$$\boxed{\frac{P_d(SR)_{CD}}{P_d(SR)_{FB}} = 1.1}$$

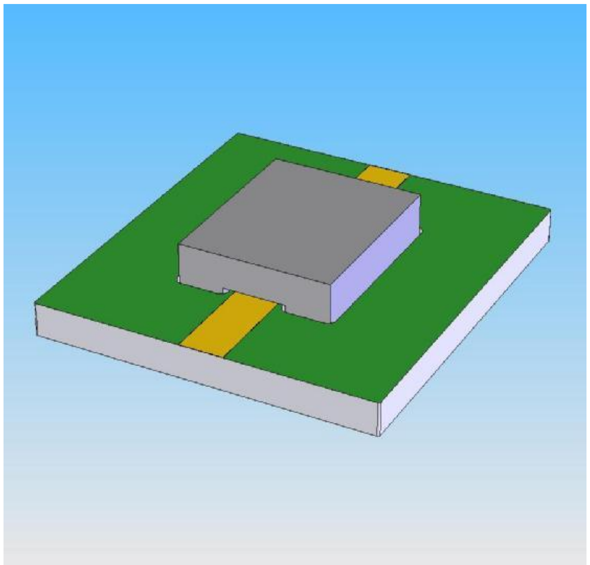
Secondary Winding Implementation



One Turn Secondary => Copper Strip Implementation

DELTA Energy Systems

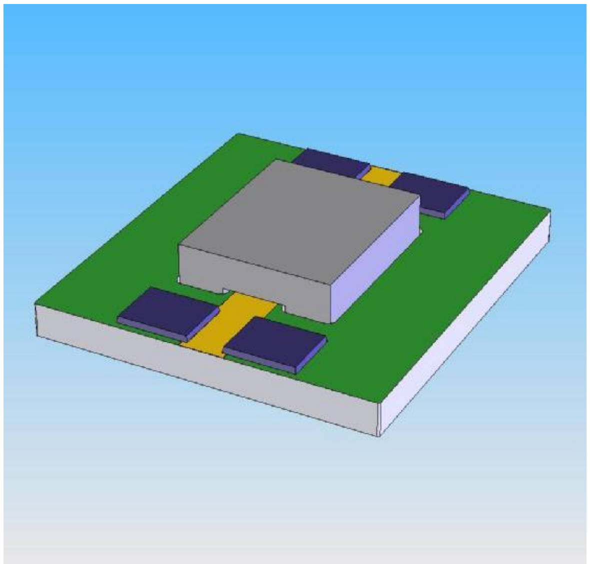
Secondary Winding Implementation



One Turn Secondary => Copper Strip Implementation

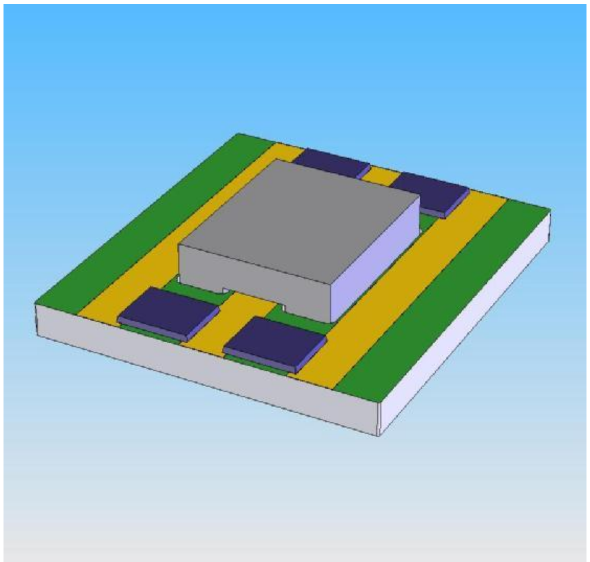
DELTA Energy Systems

Secondary Winding Implementation



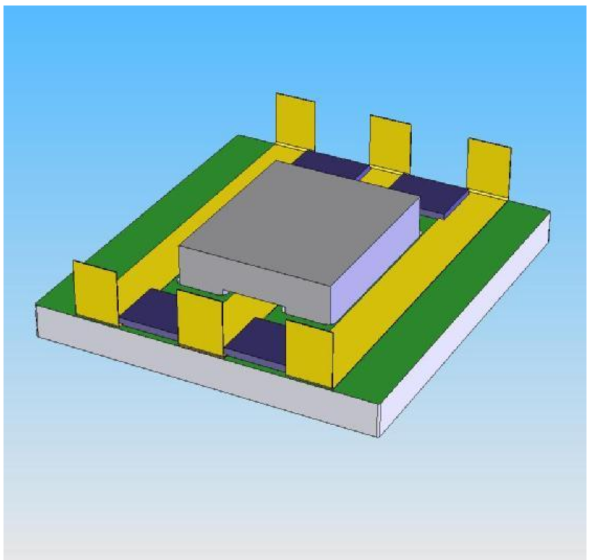
One Turn Secondary => Copper Strip Implementation

Secondary Winding Implementation



One Turn Secondary => Copper Strip Implementation

Secondary Winding Implementation

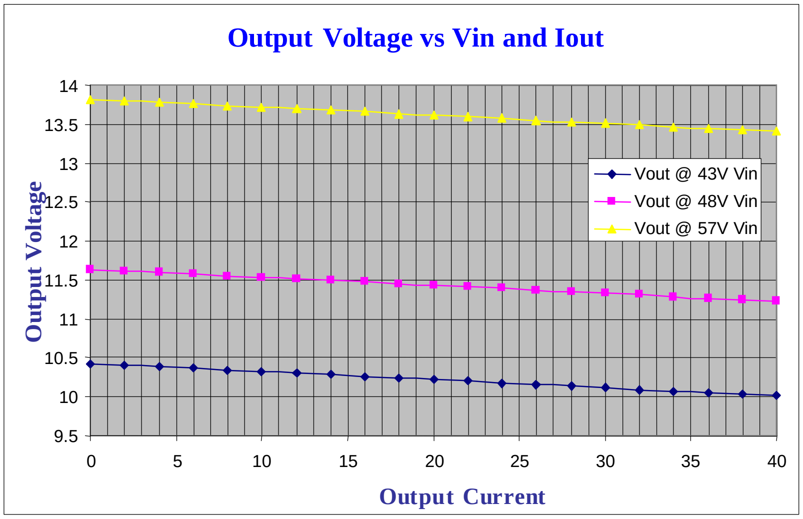


One Turn Secondary => Copper Strip Implementation

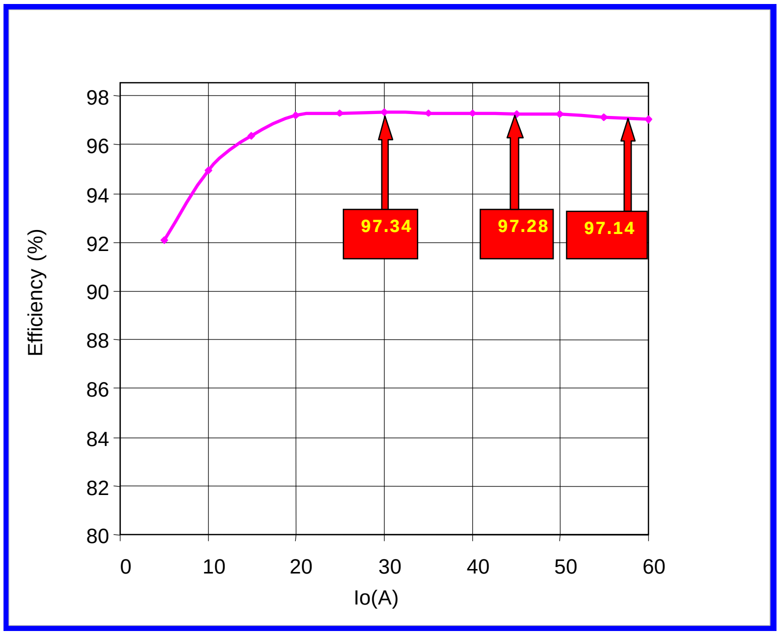
EXPERIMENTAL RESULTS

750W DC-DC Converter 12V@60A

Vout vs Vin & load



Efficiency vs Output Power



Delta Energy Systems

CONCLUSION

- 950W/inc^3 Power Density for the Power Train
- Very High Efficiency
- 6 Layers PCB & Coppers Strips

Magnetic, Packaging, Topology and Control Optimization

Delta Energy Systems

Thank You

References

[1] Wei Chen, G.Hua, Dan Sable and Fred C.Lee "Design of High Efficiency, Low Profile, Low Voltage Converter with Integrated Magnetics" APEC'97, pp.911-917

[2] J.R. Cielo " Combined Transformer and Inductor Device" US Patent 3,553,620

[3] R.Severens and E Bloom "Modern DC-DC Switchedmode Power Conversion Circuits"

[4] J.A.Bassett"Constant Frequency ZVS Converter with Integrated Magnetic" APEC 1992, pp 709-716

[5] Ionel Dan Jitaru "Transformer Providing Low Output Voltage"" US Patent # 6,400,249B1

[6] Ionel Dan Jitaru, "Fixed Frequncy Converter Switching at Zero Voltage" US Patent # 5,434,768

[7] Ionel Dan Jitaru "Low Noise Full-Integrated Multilayer Magnetic for Power Converters" US Patent 5,990,776

[8] Ionel Dan Jitaru "Packaging Power Converters" US Patent 5,973,923

[9] Ionel Dan Jitaru "Method and aparatus for transmitting a signal through a power magnetic structure" US Patent 6,414,578B1

[10] Ionel Dan Jitaru "Component Transformer" US Patent 6,466,454 B1

[11] Kevan O'Meara "A new output rectifier configuration optimised for high frequency operation" HFPC'91 pp 219-225"

[12] C.Peng, M.Hannigan, O.Seiersenm "A New Efficient High Frequency Rectifier Circuit", HFPC'91, pp.236-243

Some of the technologies presented in this seminar may be the subject of patent applications, please contact Delta Energy Systems for further details.

References

[13] Ionel Jitaru " Gapping Methodologies in Planar Magnetics" Rompower.com / January18 2010

[14] PatrizioVinciarelli " Printed Circuit Transformer" US Patent # 7,187,263 B2

[15] Jiankun Hu, C.R. Sullivan "AC Resistance of Planar Power Inductors and the Quasidistributed Gap Technique" IEEE Transactions on Power Electronics, Vol 16,no 4,pp.558-567.

[16] Ionel Dan Jitaru "Low Profile Magnetic Element"" US Patent # 7,295,094 B2

[17] Ionel Dan Jitaru "Planar Inductive Element"" US Patent # 6,967,553 B2

[18] Ionel Dan Jitaru "Ultra-planar magnetic"" Rompower.com/ January 25, 2010

[19] Ionel Dan Jitaru, "Simulation of Integrated Magnetics" Rompower.com/ February 15, 2010

[20] E.C. Snelling, "Soft Ferrites,Properties and Applications" pp.335-338

[21] PatrizioVinciarelli " Transformer with Controlled Interwinding Coupling and Controlled Leakage Inductances and Circuit Using Such Transformer" US Patent # 6,653,924B2

Some of the technologies presented in this seminar may be the subject of patent applications, please contact Delta Energy Systems for further details.