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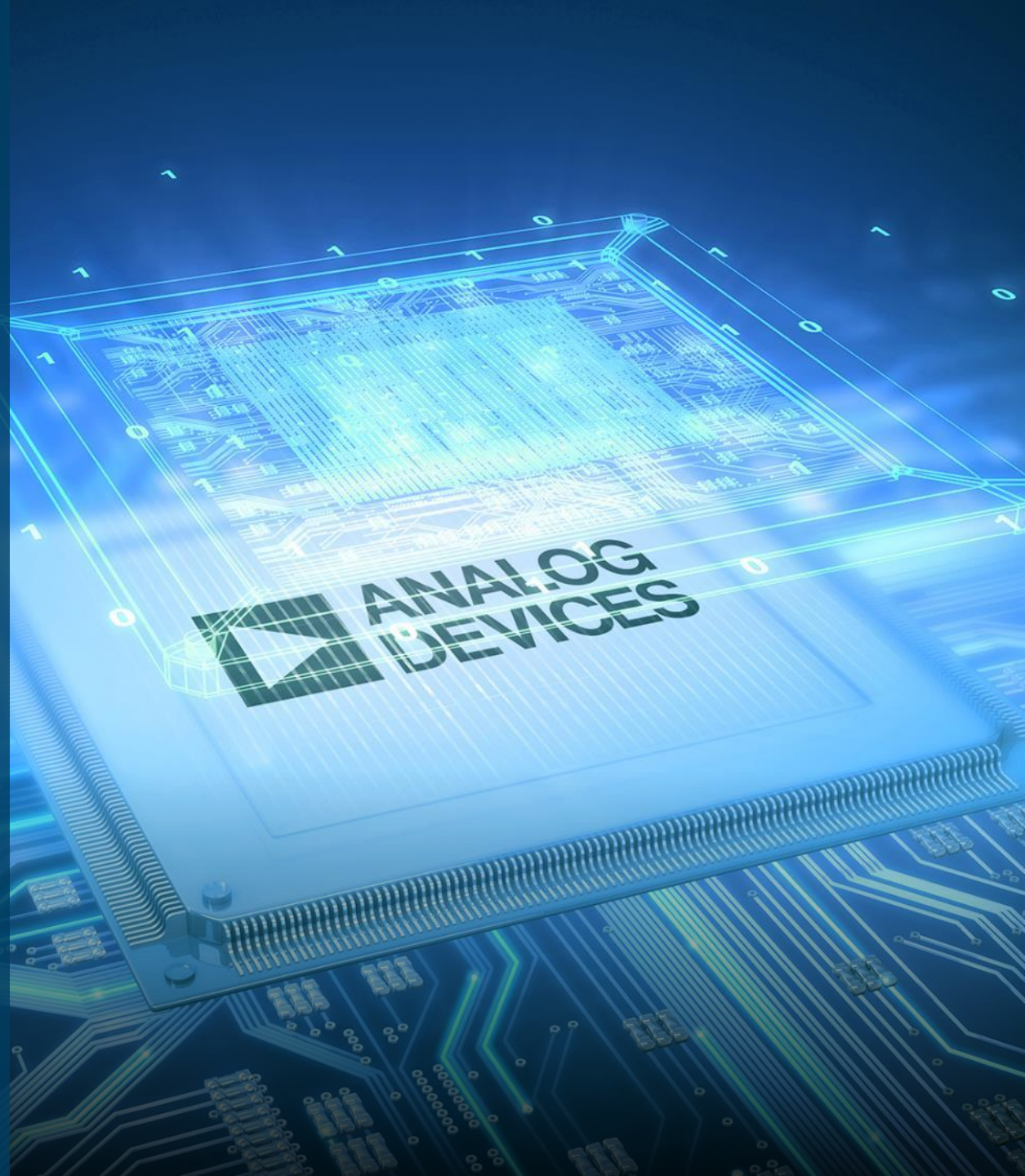
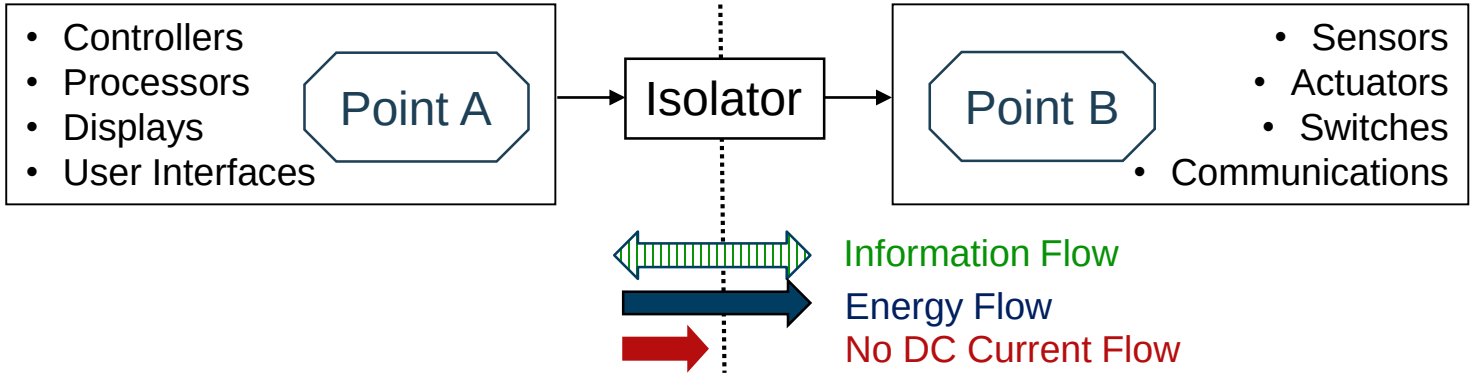
# Core and Winding Optimization of Micro-transformers for Isolated Power Conversion

BAOXING CHEN



# The Isolation Function

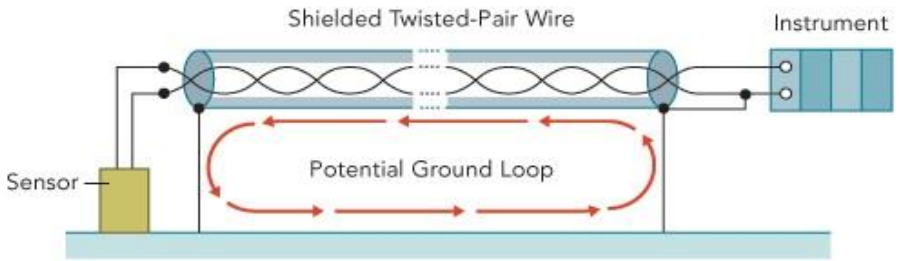
- Isolation Introduction




**Typical Application Characteristics**

- High Voltage
- High-Precision Communications
- Long-Distance Communications

- Isolation Function
  - provides means for wired communication without DC connection and it provides protection, the safety and accuracy needed.
- Benefit of Isolation
  - Protect people/equipment from hazardous voltages or transients
  - Prevent ground loops from compromising the measurement accuracies



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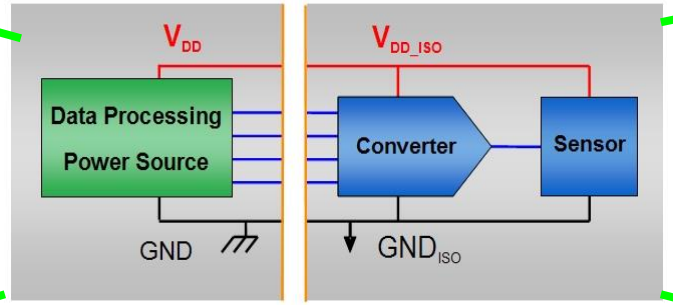
# Isolation Applications

PLC
I/O & Communication

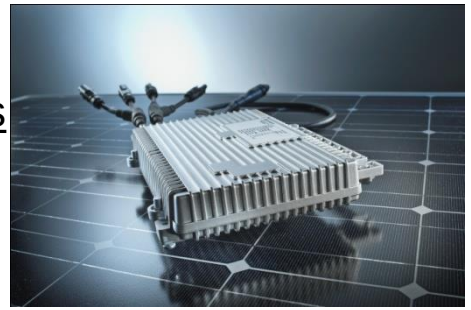
EV
BMS and Electric Drive

Instrumentation
Data Acquistion & Communication


Motor Control
Sensing & Gate Drive

PV
Inverters



Patient Monitoring
To/from Patient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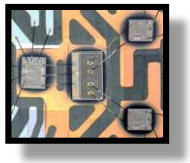
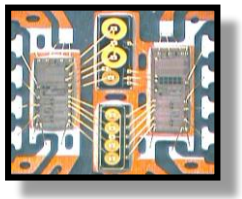
# ADI has Shipped > 2 Billion Micro-Transformers for Signal and Power Isolation

**ADuM140x**
4 Channels in One Package



**ADuM1220**
½ Bridge Gate Driver



**ADuM540x**
*iso*Power®

**ADuM4160**
USB

**ADM2582**
RS-485 with *iso*Power

**ADuM124x/144x**
Ultra Low Power Isolator

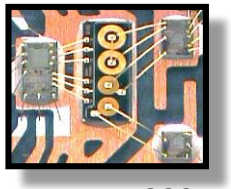
**ADE791x**
Isolated Metering AFE

**ADuM14x**
Robust Quad Data

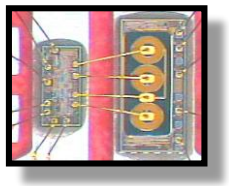
**ADN4651**
600Mbps Isolated LVDS

**ADuM502x**
Low EMI isoPower

**ADuM240x**
5 kV rms Isolation



**ADuM5230**
½ Bridge Driver with isoPower

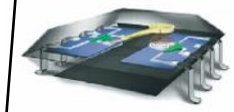


**ADM248x**
RS-485

**ADuM1100**
First *i*Coupler Digital Isolator

*i*Coupler®

**ADuM120x**
2 Channels in Narrow SO-8

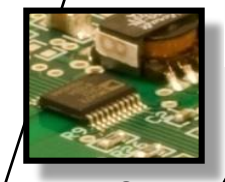


**AD7400**
ΣΔ ADC

**ADuM125x**
I²C

**ADM3251E**
RS-232

**ADuM7410**
1 kV rms



**ADuM347x**
Switching Regulator

**ADM305x**

**ADuM3190**
Linear Isolator

**ADuM4135**
IGBT Gate Driver

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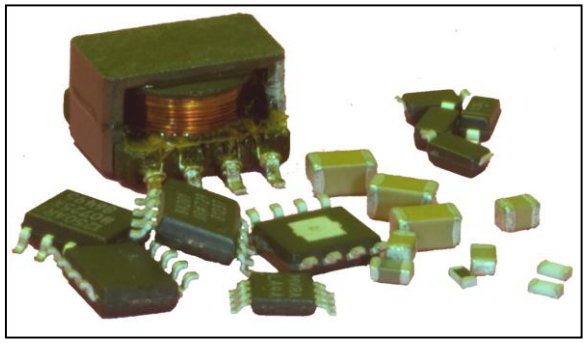
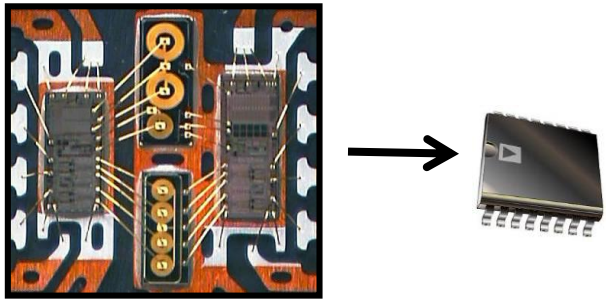
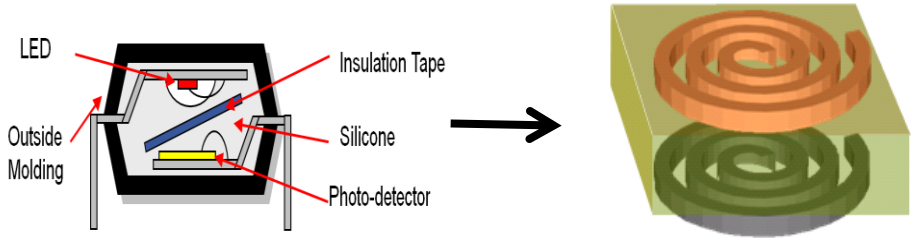
# Micro-Transformers Replace Discrete Transformers, Diodes & Opto-couplers



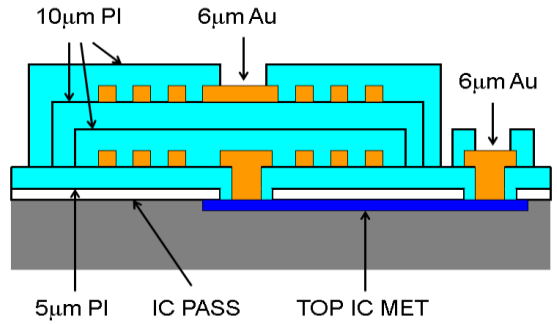
Conventional, Discrete Solution

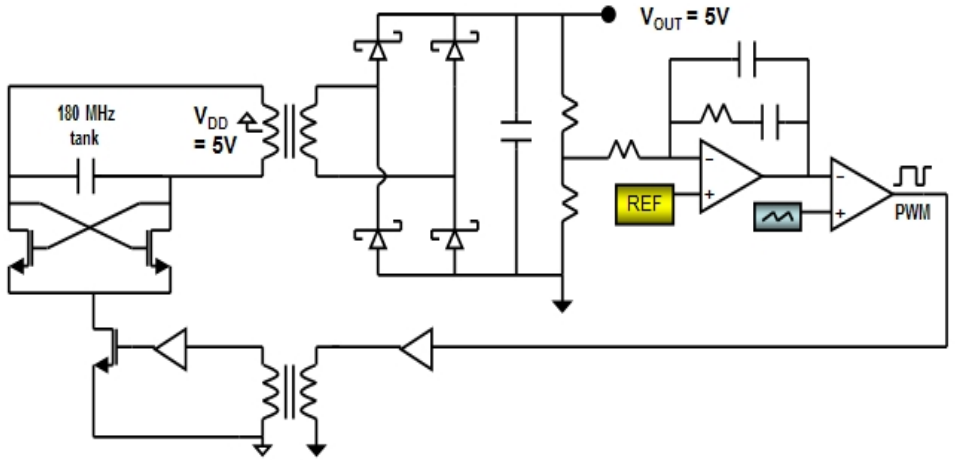


½ W Isolated Power & 4
High Speed Data Channels

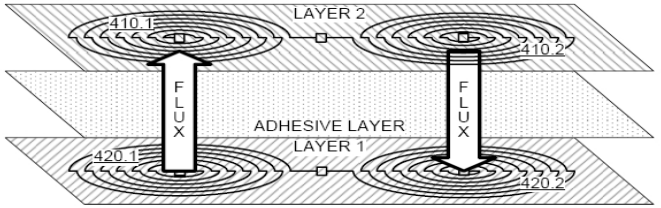


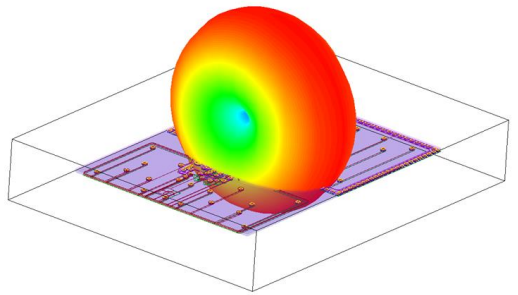

**High speed, low power and integration**




- **High-freq energy conversion**
- **low-freq energy regulation**



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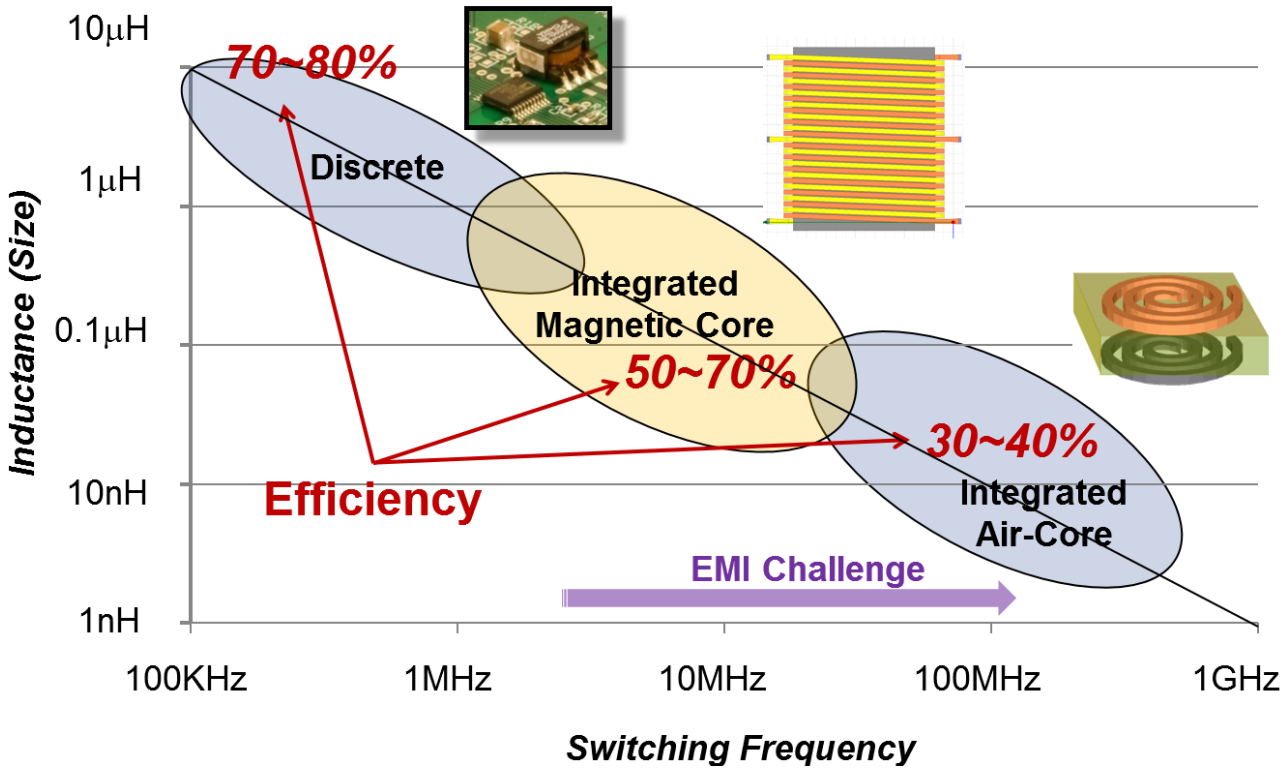
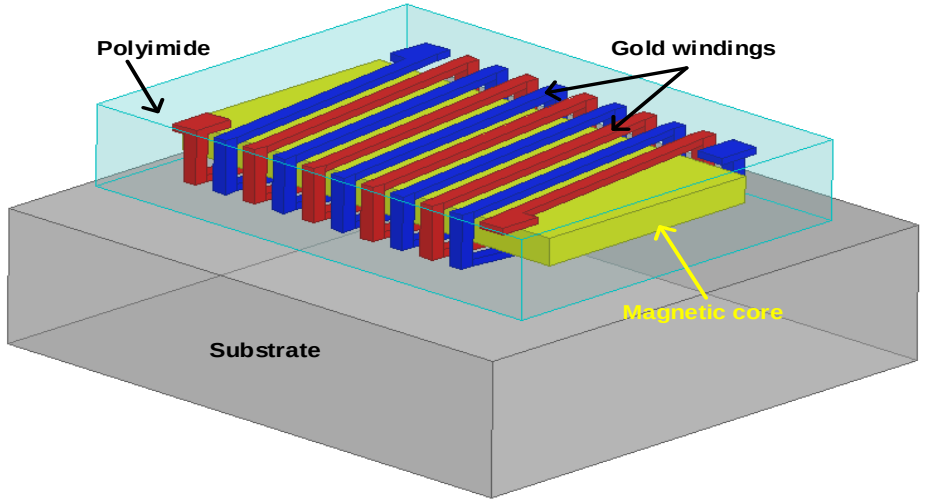
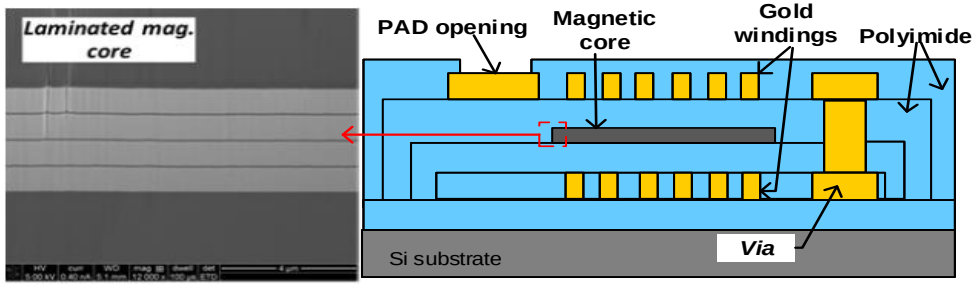
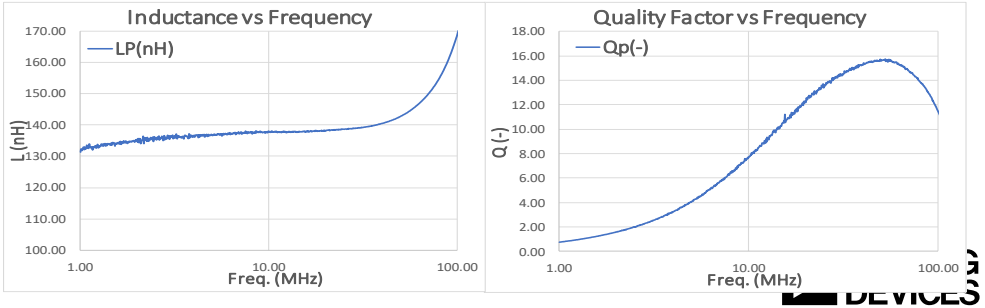
# Magnetic Core Transformer Improves Efficiency and Reduces EMI

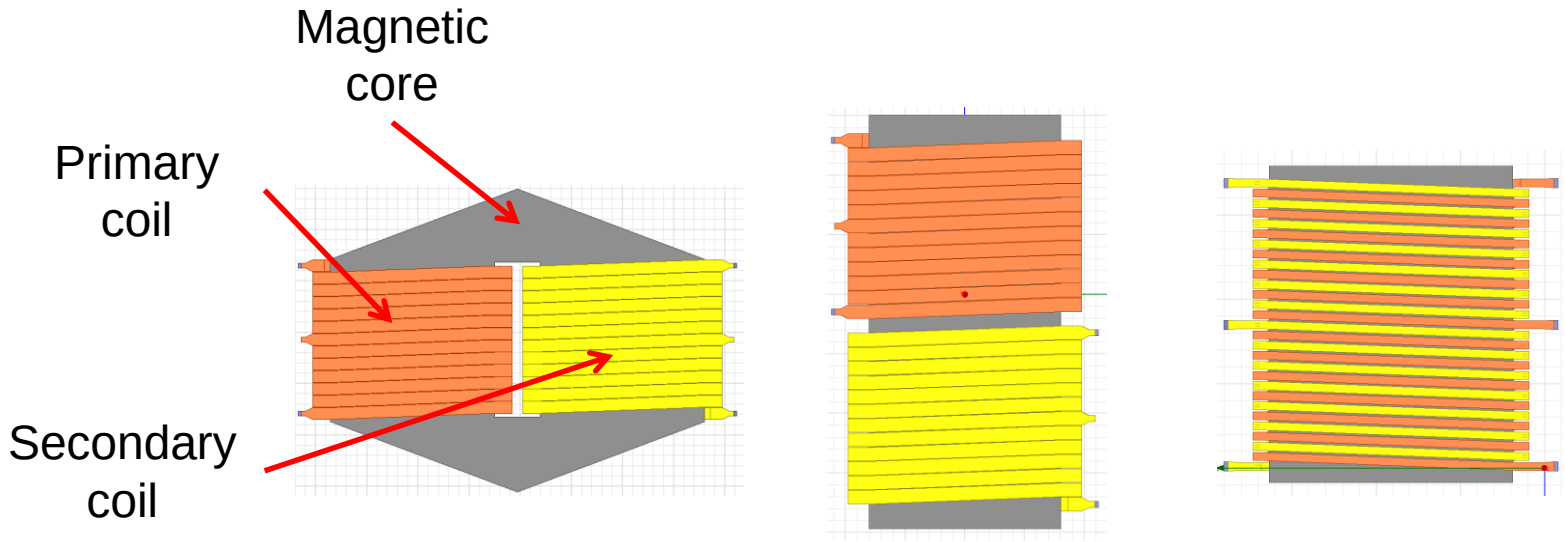


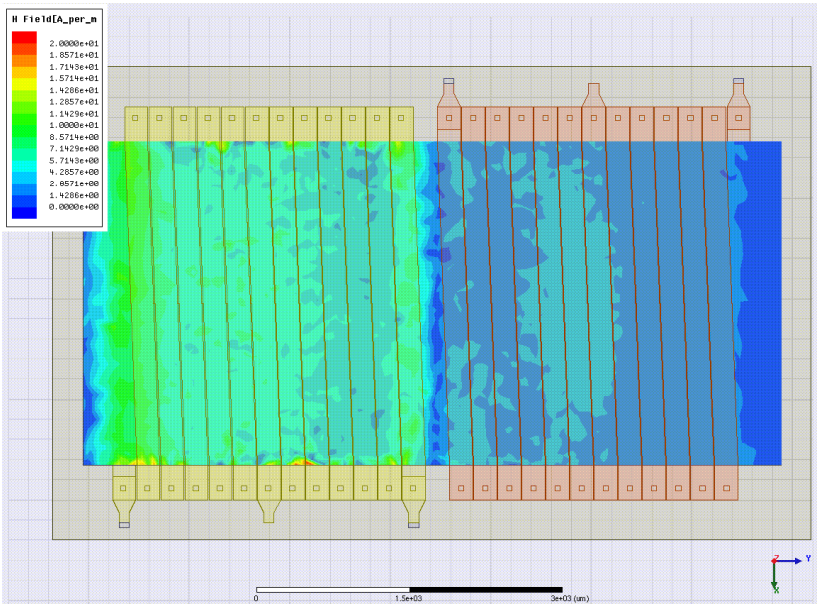



# Coupling Choices for Transformer Windings



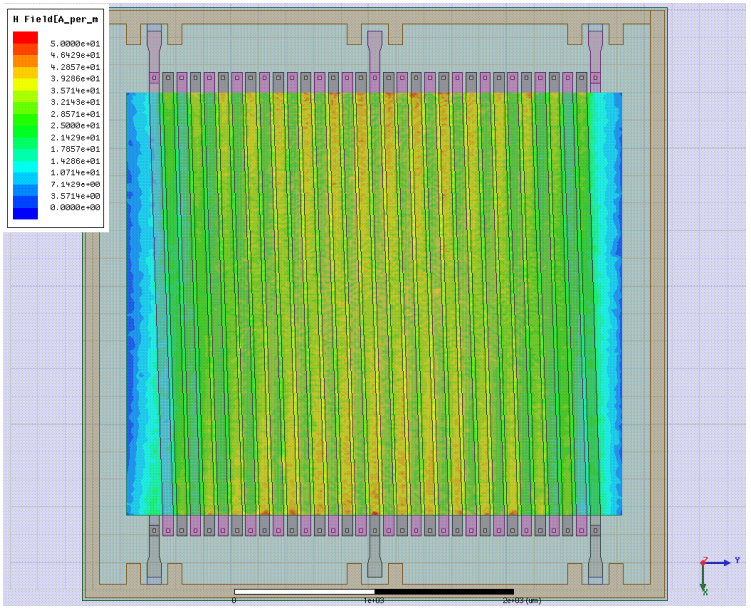

| | Toroidal | Solenoidal - Separated coils | Solenoidal – co-wound coils |
|---|---|---|---|
| Pros | Isolation | Isolation | Coupling |
| Cons | Coupling, Anisotropic core | Coupling | Isolation |

# Tight Magnetic Coupling Through Intertwined Windings Including Step Up




**Separated coils**

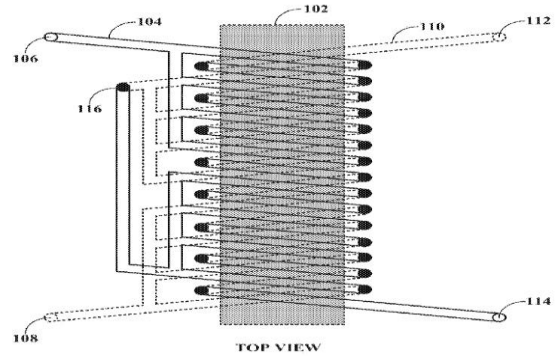
k~0.1



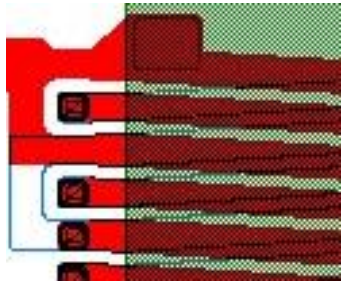

**Co-wound coils**

k~0.9

**Patent (US8786393B1):**




**Step Up Solution:**
parallel turns in primary coil



**Co-wound coils necessary to maximize coupling factor.**



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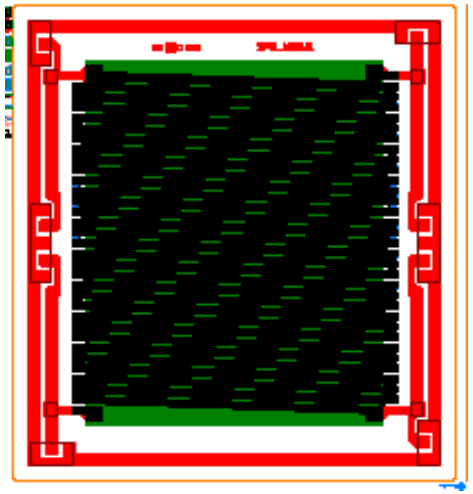
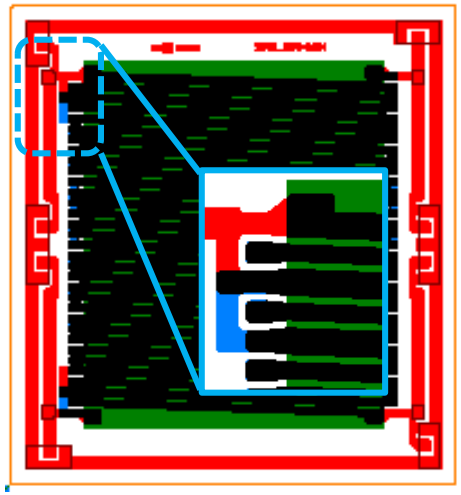
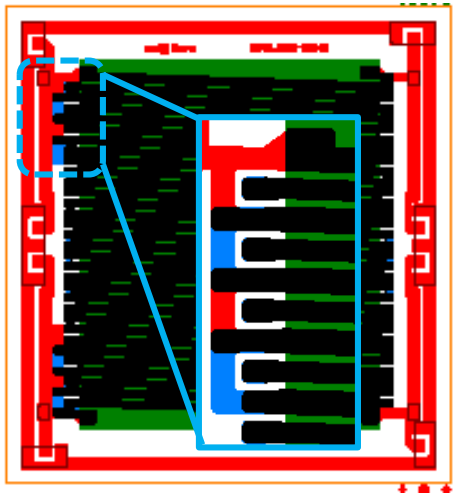
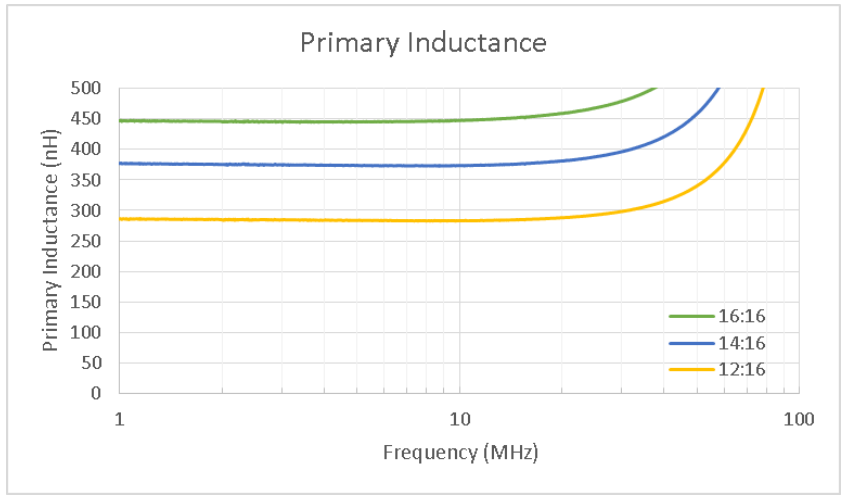
# Step-Up Winding Examples

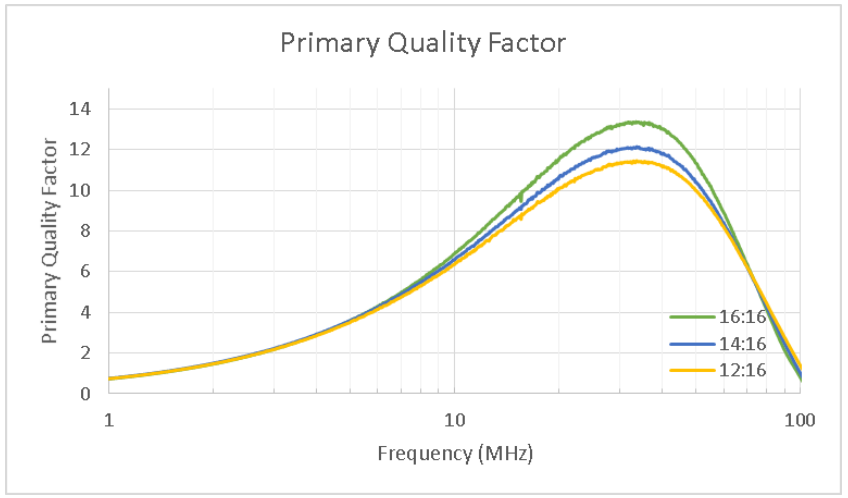
| Winding ratio | 16:16 | 14:16 | 12:16 |
|---|---|---|---|
| Layout Example |  |  |  |
| Step-up Ratio Achieved | 1 | 1.09 | 1.25 |
| Coupling Coefficient Achieved | 0.933 | 0.927 | 0.917 |

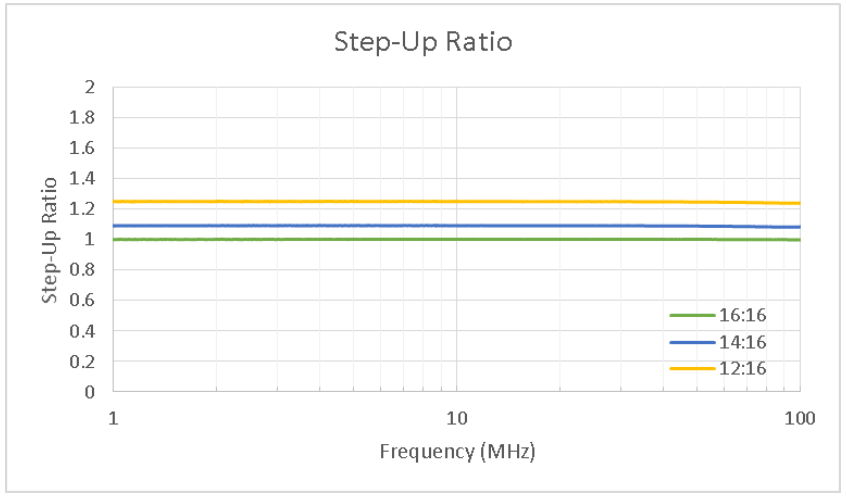
* All 3 designs have the same core size, winding width, and winding-to-winding separation

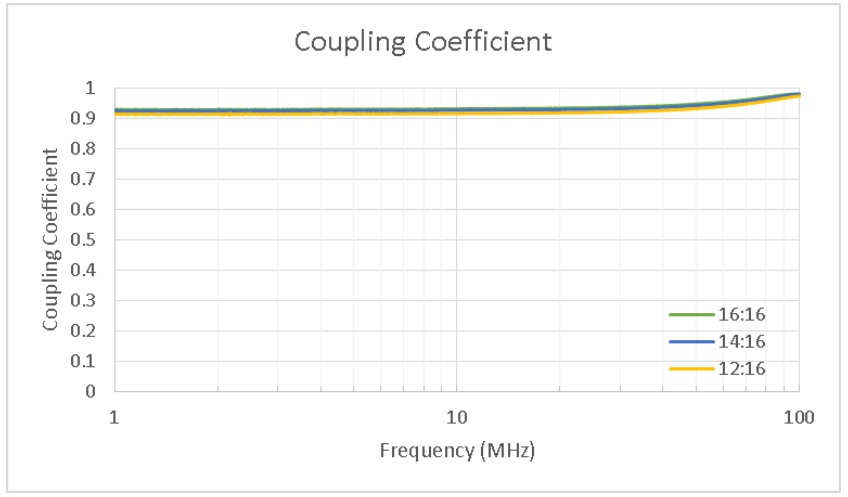
**12:16 design achieves 25% step-up ratio with only 1.7% reduction of coupling coefficient**

# Transformer RF Performance



# Quality Factor Enhancement through Segmented Core

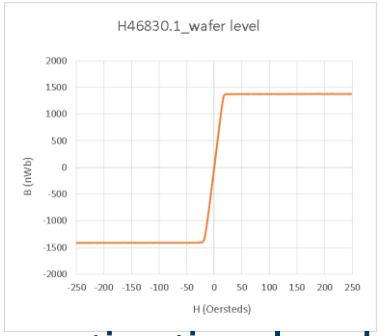
$$L = \frac{\mu_0 \mu_r N^2 w t_m}{l}$$

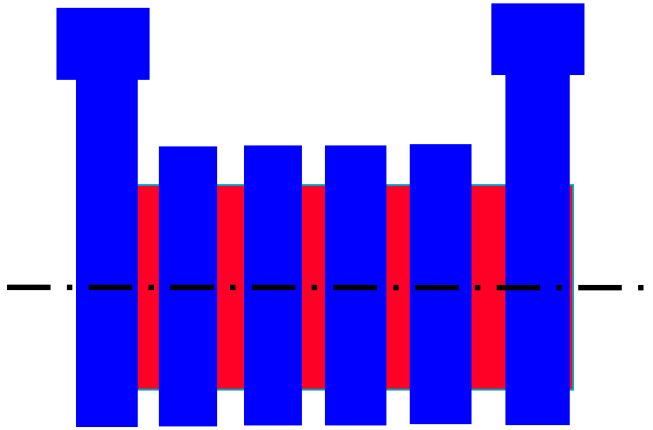
$$R_{dc} = \frac{2Nw\rho}{w_c t_c}$$

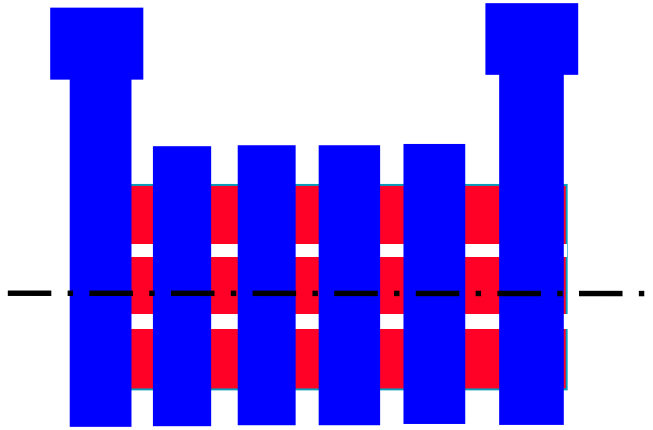
$$Q = \frac{\omega L}{R} = \frac{\omega \mu_0 \mu_r N t_m w_c t_c}{2l\rho}$$

$$L = \frac{\mu_0 \mu_{rg} N^2 (w - 2wg) t_m}{l}$$

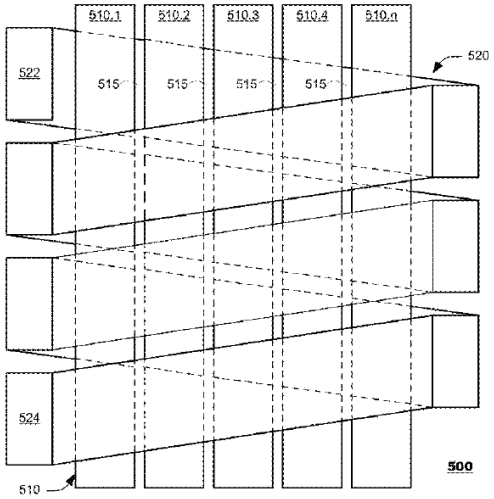
$$M = M_s \frac{H}{H_a} = \mu H$$



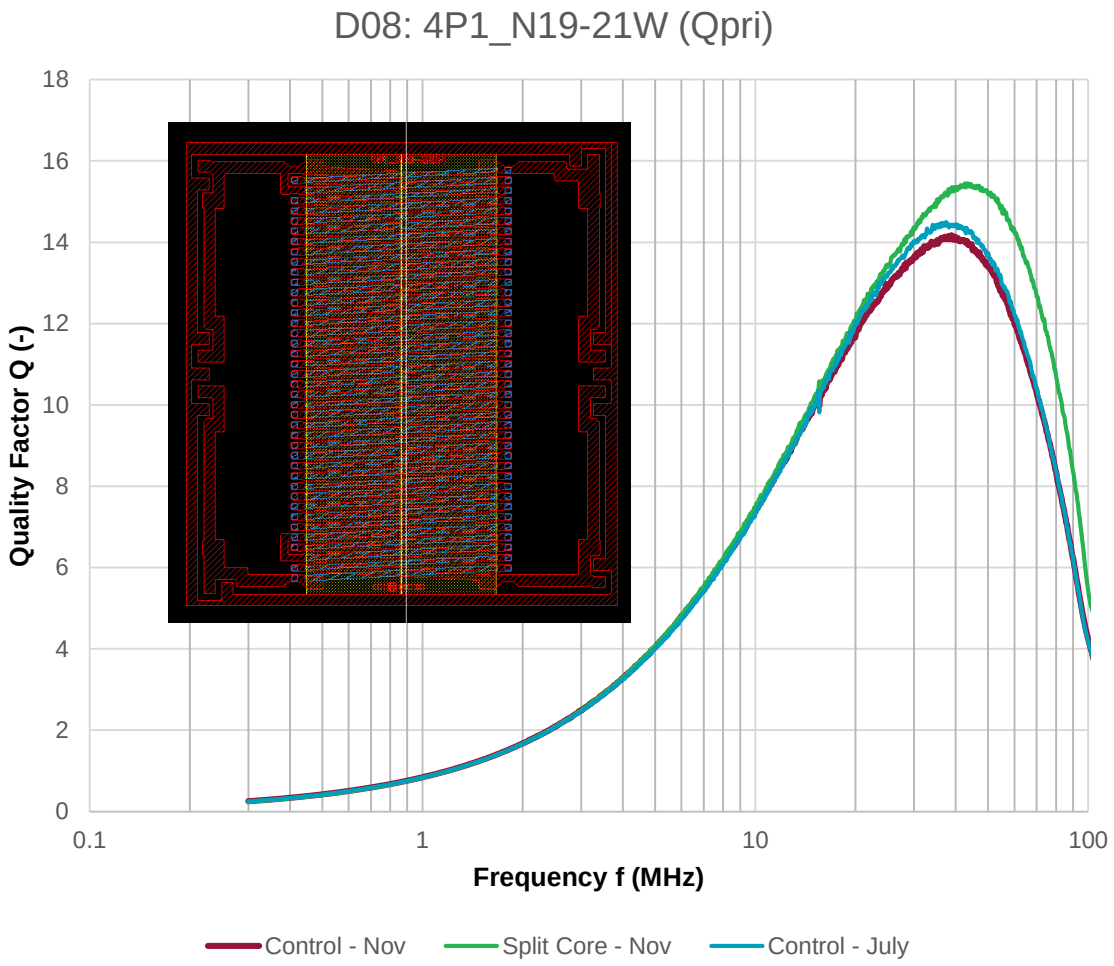


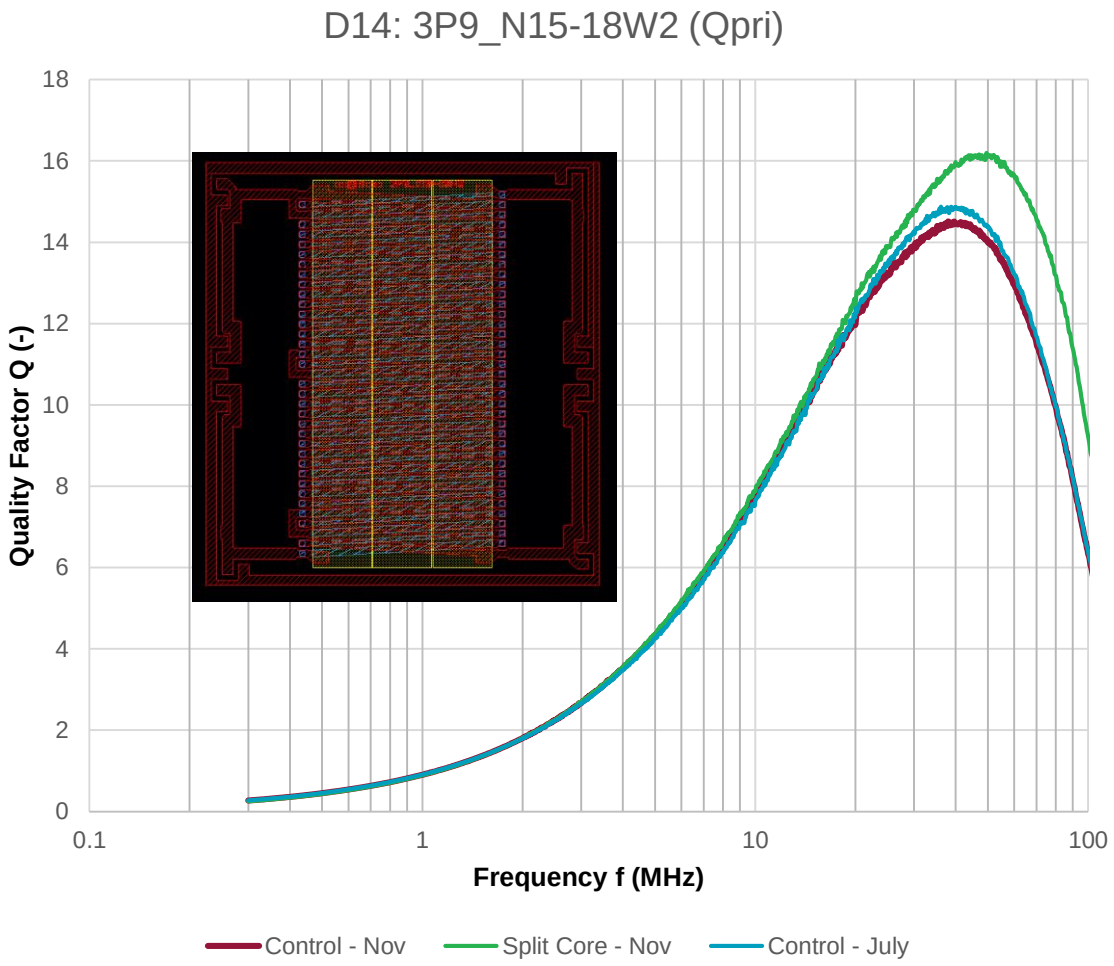
Patent (US9,640,604B2)




Shape anisotropy or demagnetization lead to small Ha or larger effective permeability

# Core Optimization Results





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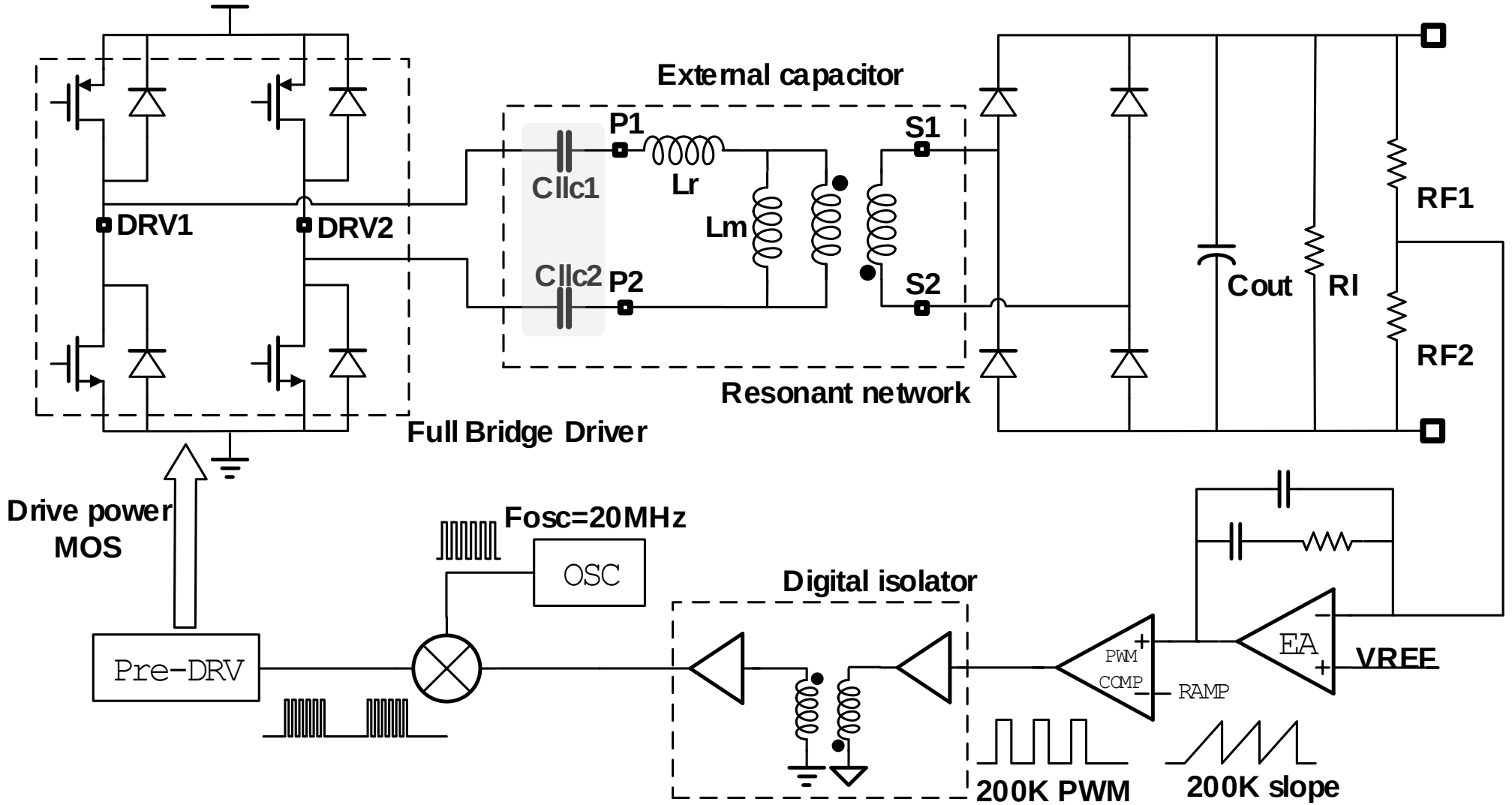
# Symmetric LLCC Resonant Converter For Low EMI




*Flow Zhao et al, CICC 2017



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# Fully Integrated 5kVrms Isolated DC/DC Converter: Class B EMI; >1W; Peak η ~ 52%

*Yue Zhuo et al, ISSCC 2019

# Summary

- Micro-transformers achieves Q>16 with k>93%
- Step up transformers with tight magnetic coupling were achieved through selected parallel connections for the primary windings
- Transformer Q can be enhanced by >10% with segmented core
- >1W with >52% efficiency fully integrated 5kVrms isolated DC/DC converter was achieved with micro-transformers

***Acknowledgements: Contributions from iCoupler® group & ADLK FAB ipassive team in ADI especially Yuanyuan Zhao, Jan Kubik, Flow Zhao, and Yue Zhuo***