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Introduction to:

GaN-Ready Magnetics

Purpose

- Discuss Advantages of **GaN-Ready Magnetics** and Precision's capabilities

Topics

- Introduction to GaN Magnetics
- Benefits of GaN Switches
- Precision Expertise
- Applications
- Technology Partners

Content

- 22 Pages

Learning Time

- 10 Minutes

Welcome to the Precision GaN ready magnetics training module. This module will provide an introduction the benefits of GaN switch technology before exploring the technical requirements and benefits of GaN ready magnetics used in these applications. Technology benefits and applications are outlined as are key areas of Precision expertise.

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In a Nutshell….

Advantages of GaN Technology

- Reductions in system volume, weight and size
- Higher operating temperatures / reduced heat sink requirements
- Lower switching losses / increased power output
- High breakdown strength, maximum current & oscillation frequency

Precision Expertise: GaN-Ready Magnetics

- LLC Transformers and PFC Inductors
- Core Material Selection
- Parasitic Management
- Extensive stock of Litz wire
- Partnerships with industry-leading GaN Switching technology suppliers including **Transphorm** and **International Rectifier**

GaN technology offers a number of advantages including reductions in system volume, weight and size, higher operating temperatures with reduced heat sink requirements, lower switching losses /increased power output as well as high breakdown strength, high maximum current and high oscillation frequency. Precision offers GaN ready LLC transformers and PFC inductors. Our GaN-ready magnetics expertise includes core material selection, excellent parasitic management and extensive Litz wire selection. Precision has worked with industry-leading GaN switch technology suppliers to help design and create high performing GaN-ready magnetics.

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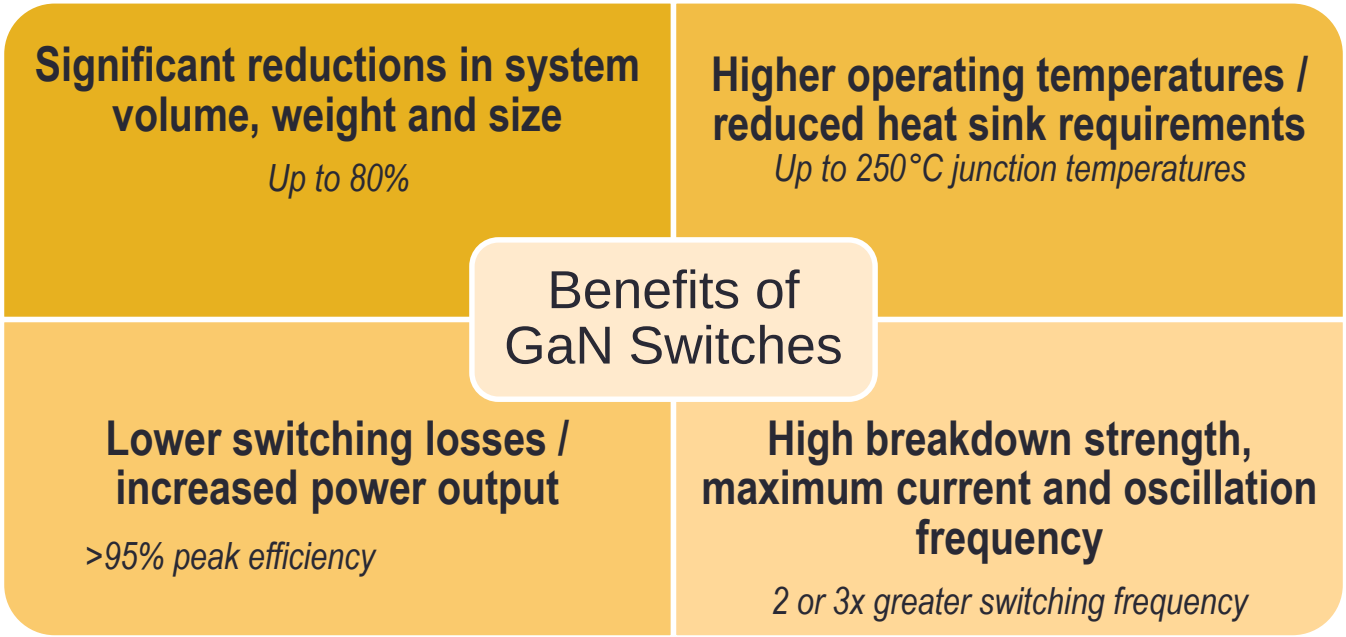
GaN Switches: Benefits



GaN devices can be switched at two or three times higher frequencies offering a number of benefits over Silicon technologies. They provide significant reductions in system volume, weight and size and offer higher operating temperatures with reduced heat sink requirements. The lower switching losses result in increased power output. GaN switches also have a high breakdown strength, high maximum current and high oscillation frequency.

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What are GaN-Ready Magnetics?

GaN-Ready Magnetics are performance and size-optimized magnetics for high frequency switching applications.

- Power up to 1 KW at up to 500 kHz
- Power from 1-10 KW at up to 250 kHz

GaN-Ready Magnetics are performance and size-optimized magnetics for high-frequency switching applications. At powers of up to 1 KW switching frequencies are up to 500 kHz . At powers ranging from 1-10 KW switching frequencies are up to 250kHz. These magnetics have specially selected cores and parasitic management to ensure optimal performance in high switching applications.

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Precision's GaN-Ready Magnetics Expertise:

LLC Inductors

PFC Transformers

Core Material Selection

Excellent Parasitic Management

Extensive Litz Wire Selection

Precision offers GaN-ready LLC inductors and PFC transformers. Our GaN-ready magnetics expertise includes core material selection, excellent parasitic management and extensive Litz wire selection.

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Precision Expertise: Core Material Selection

Technical Challenge

- Core material performance depends on ***both*** switching frequency and operating temperatures.
- Losses can go up 50% at various temperatures on a given core material.

Why This Matters

- GaN switches are designed for higher switching frequency and for higher operating temperatures.
- Expert core material selection is key to ensuring optimal magnetics performance in these conditions.

Precision Expertise

- Deep understanding of ***over 50 core materials***
- Insight into how these materials perform at different frequencies and operating temperatures.
- Ability to indentify best core material for each unique application

Precision understands that each core material has different characteristics and that the performance of each core material will depend heavily on the switching frequency as well as on the operating temperature. Given that GaN switches have high switching frequencies and the ability to perform at higher operating temperatures, strategically selecting core materials capable of providing optimum magnetic performance is key. Precision works with more than 20 core suppliers and has a deep understanding of the performance characteristics of over 50 core materials. This deep expertise in core material selection allows Precision to provide optimized magnetics for GaN switching applications.

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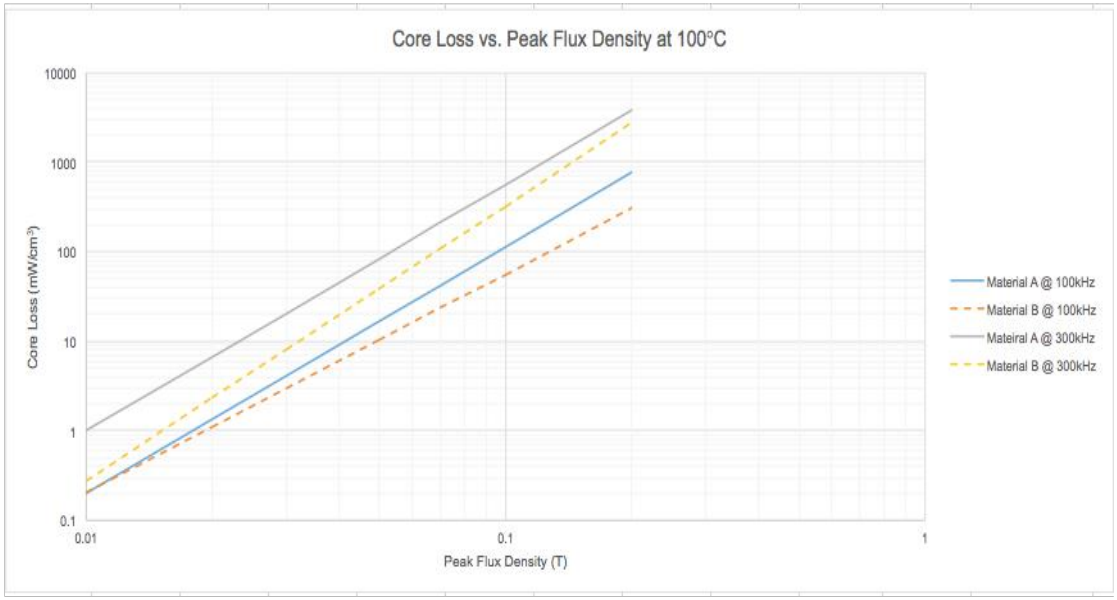
Precision Expertise: Core Material Performance & Switching Frequency

Figure 1: Material A vs. Material B



Material A:

- ***5X times more*** core loss when operating at 300kHz compared to 100kHz switching frequencies
- To achieve the same core loss at 100kHz & 300kHz, 300kHz operating peak flux density must be de-rated by 44% from 100kHz

Material B:

- Operating at a higher peak flux density allows turns reduction to be 2.21x
- ***32% improvement*** compared to Material A helps further reduce conduction loss and winding capacitance

In Figure 1, Material A exhibits five times more core loss when operating at 300kHz compared to 100kHz switching frequencies, assuming a common 0.1T peak flux density. Another way to interpret such a difference is that in order to achieve the same core loss at both 100kHz and 300kHz, the 300kHz operating peak flux density must be de-rated by 44% from that at 100kHz. A common misconception is that as operating frequency increases three times, in this case from 100kHz to 300kHz, the number of turns can be reduced by the same ratio. However, the gain in turns reduction is not directly proportional to the increase in switching frequency. Taking the above peak flux density de-rating into consideration, in order to achieve the same core loss, the turns reduction is 1.7 times instead of three times. Better core material selection can reduce loss variability with switching frequencies. As demonstrated in Figure 1, Material B is a better choice for 300kHz switching frequencies as the required peak flux density is 0.07T in order to achieve the same 100mW/cm3 core loss. Being able to operate at a higher peak flux density allows the turns reduction to be 2.21 times. This is a 32% improvement when compared to Material A at 1.68 times turn reduction.

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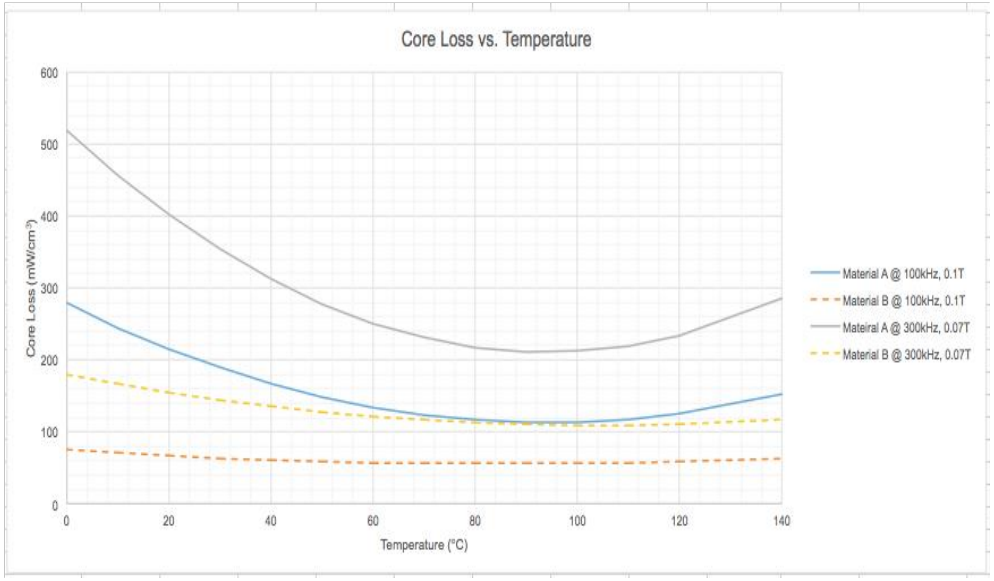
Precision Expertise: Core Material Performance & Operating Temperature

Figure 2: Core Loss Variance vs. Temperature for Material A vs. Material B



Material A:
-Lowest core loss near 100˚ C
-Core loss is 50% higher at 40˚ C and 10% higher at 120˚ C

Material B:
-Core loss more stable over temperature
-Loss variance between 40˚ C and 100˚ C within 10% from its minima

Conclusion:
- Selecting Material B over Material A can greatly enhance efficiency.

Figure 2 shows the core loss variance versus temperature for Materials A and B at 100kHz and 0.1T. Material A exhibits its lowest core loss around 100˚ C. However, core loss can vary greatly with operating temperature. For example, for Material A, core loss is 50% higher at 40˚ C and 10% higher at 120˚ C than was the case at 100˚ C. On the other hand, the core loss of Material B remains a lot more stable over temperature with loss variance between 40˚ C and 100˚ C within 10% from its minima. The important role of operating temperature is often overlooked in an industry where it is common practice to chart core loss curves at a fixed temperature, most often the minim. Selecting the proper core material for your application´s operating temperature can have a significant impact on efficiency. In this figure, selecting Material B over Material A might make the difference between an 80 Plus Platinum and 80 Plus Titanium efficiency certification.

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Precision Expertise: Parasitic Management

Both **leakage inductance** and **capacitance** contribute to switching losses.

Leakage Inductance:
Will want to ***minimize*** or ***maintain*** based on unique application requirements.

Capacitance:
Will want to ***minimize***.

Precision provides precise leakage inductance and capacitance management through 3D finite element analysis & *winding configurations*

Both leakage inductance and capacitance contribute to switching losses. Leakage inductance has been known to create voltage spikes during switching. Depending on their unique application, design engineers will want to minimize or maintain leakage inductance. In nearly all cases design engineers will be looking to minimize capacitance. To achieve precise parasitic management, Precision uses both 3D finite element analysis and a variety of winding configurations.

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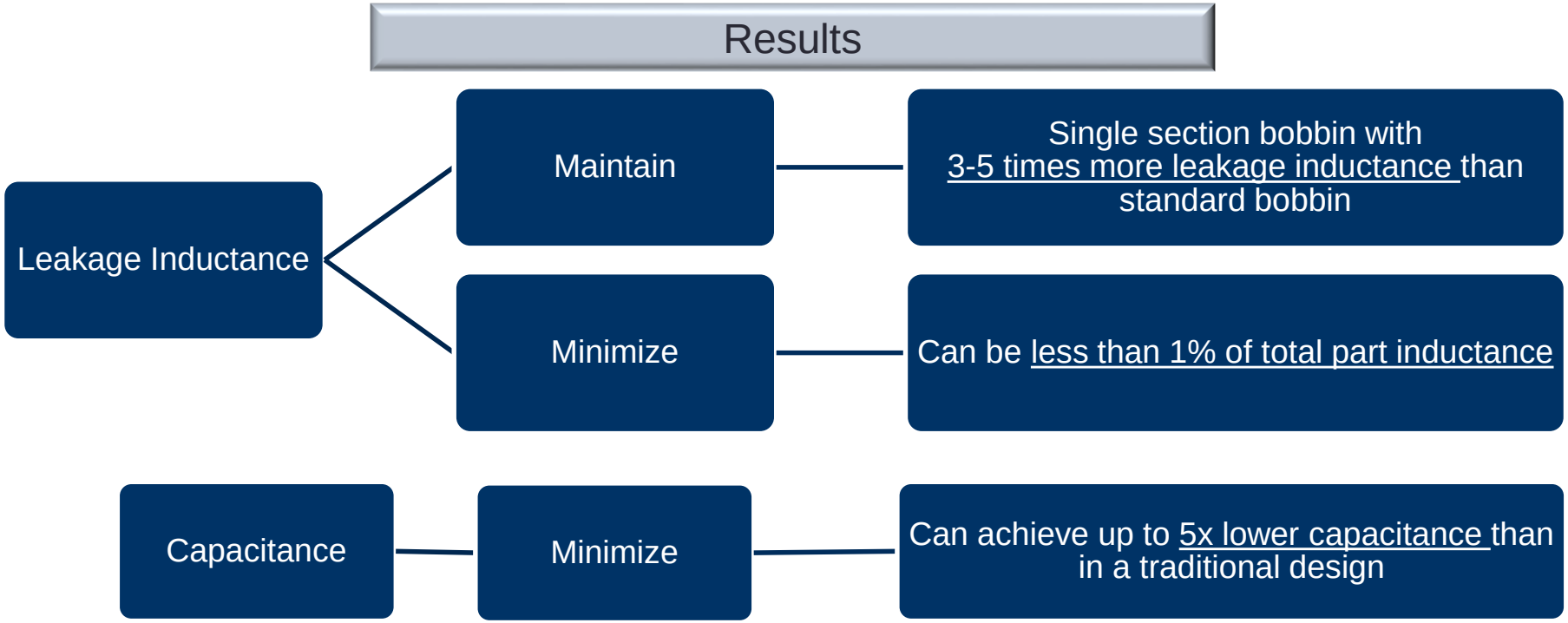
Precision Expertise: Parasitic Management



Using a combination of Finite Element Analysis and advanced winding configurations, Precision can precisely manage both leakage inductance and capacitance paracetics. For design engineers looking to maintain leakage inductance, Precision can create a single section bobbin that provides three to five times more leakage inductance than a traditional bobbin. This is done using a single section bobbin where the primary and secondary windings are concentrically wound. For those looking to minimize leakage inductance, Precision can design magnetics in a way that leakage inductance accounts for less than one percent of total part inductance. Additionally, Precision can achieve up to five times lower capacitance than traditional magnetic designs.

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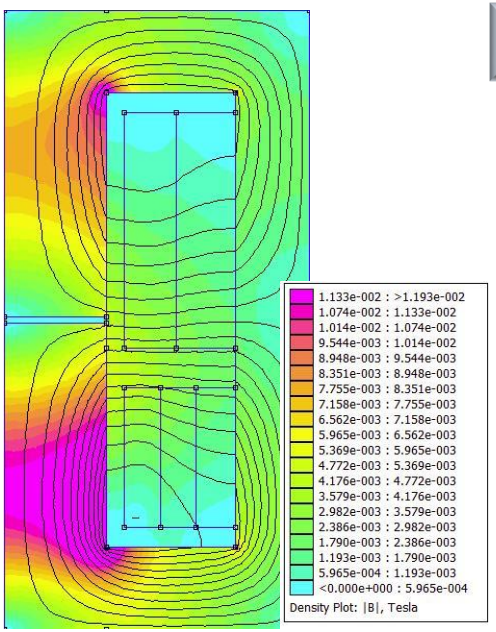
Precision Expertise: Parasitic Management



Method: 3D Finite Element Analysis

- ✓ Speeds time to market by ensuring performance is optimized from the beginning- eliminating the need for design reiterations.
- ✓ Electromagnetic properties are modeled and investigated with advanced Maxwell 3D simulation software from Ansys
- ✓ Enables precise management of both leakage inductance and capacitance parasitics.

3D Finite Element Analysis is used to analyze magnetic flux distribution. It can be used to analyze leakage inductance and losses due to skin and proximity effects. Electromagnetic properties are modeled and investigated with advanced Maxwell 3D simulation software from Ansys. In addition to ensuring optimal performance, finite element analysis speeds time to market by ensuring performance is optimized from the beginning- eliminating the need for design reiterations.

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Precision Expertise: Parasitic Management

Method: Advanced Winding Configurations

Bobbin Wound

Toroid Wound

- ✓ Precision has market-leading expertise in magnetic winding configurations.
- ✓ Capability to identify advanced winding configurations to minimize parasitics in each unique application.
- ✓ Both bobbin wound and toroid wound options.

Precision is a market leader in magnetic winding configurations. Our design team is highly qualified to identify advanced winding configurations designed to minimize parasitcs in each unique application. Both bobbin wound and toroid wound options are available.

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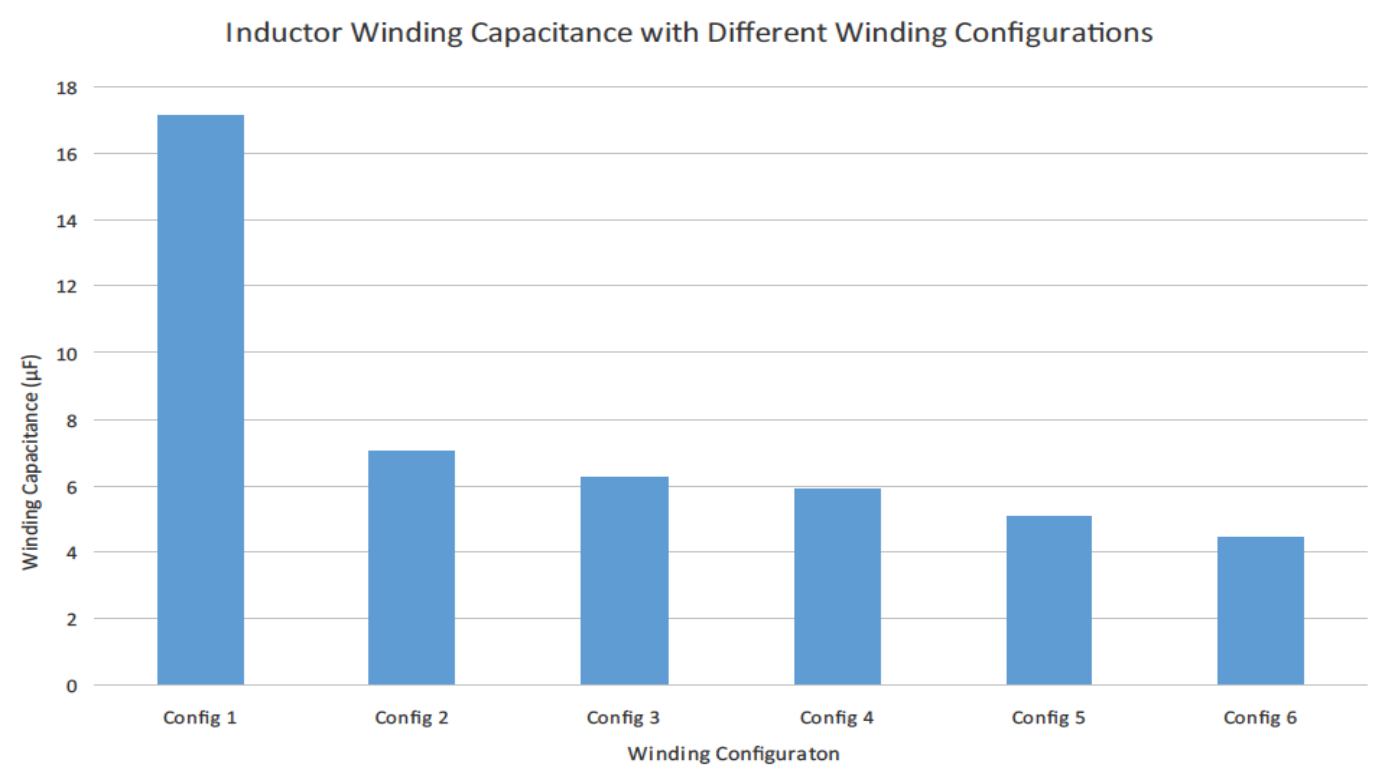
Precision Expertise: Parasitic Management

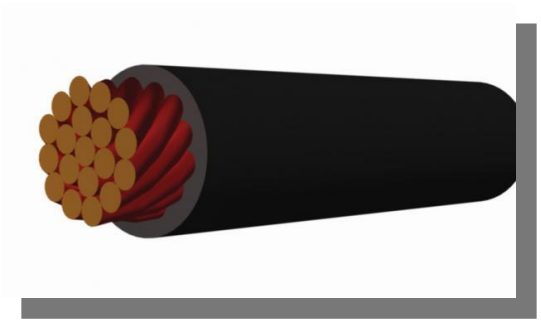


Capacitance can vary as much as *75%* depending on winding configuration

*All winding configurations have the same core, bobbin and the number of turns

The same magnetic component with the same bobbin, number of turns and package style can have significantly different capacitance dependent on the winding configuration. As you can see in, capacitance can vary as much as 75% dependant solely on winding configuration.
Be sure any potential GaN-ready magnetic supplier has the advanced winding (both bobbin wound and toroid wound) expertise to minimize parasitics in each unique application.

Precision's Expertise: Extensive Litz Wire Selection



- Extensive stock ensures customers get the most optimized product in shortest amount of time
- Sizes Available:
  - 36 AWG to 48 AWG individual strand
  - 2AWG to 41AWG equivalent wire gauge

Precision´s expert technical support is enhanced by the company´s extensive stock of litz wire, ensuring that customers can get the most optimized product, in the shortest amount of time. Litz wire is available in a number of sizes including 36 AWG to 48 AWG individual strands and 2 AWG to 41 AWG equivalent wire gauge.

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Precision's Expertise: Litz Wire – Skin Effect & Proximity Effect

What is Skin Effect?

As switching frequency increases, current tends to travel on the outside of the conductor, increasing its AC resistance.

The skin depth of a conductor at a given frequency is the penetration distance from the surface towards the center of the conductor.

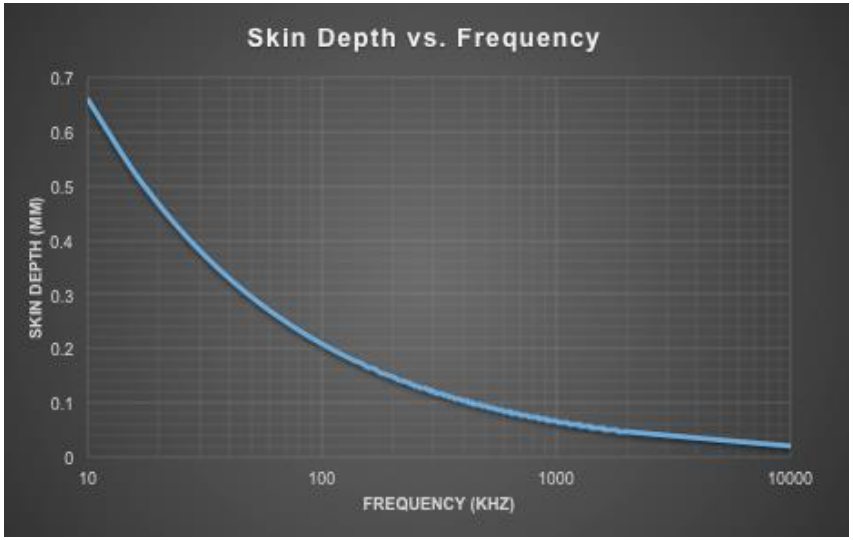
What is Proximity Effect?

A critical contributor to AC resistance which is the current redistribution within a conductor caused by the current flowing in an adjacent conductor. Depending on the design, Proximity Effect can increase the AC resistance of a transformer or inductor by 10 to 100 times more than Skin Effect can.

As switching frequency increases, current tends to travel on the outside of the conductor, increasing its AC resistance. This phenomenon is called Skin Effect. The skin depth of a conductor at a given frequency is defined as the penetration distance from the surface towards the center of the conductor. Skin Effect, however, is only a part of AC resistance that hinders overall efficiency. Another critical contributor to AC resistance is the Proximity Effect which is the current redistribution within a conductor caused by the current flowing in an adjacent conductor. Depending on the design, Proximity Effect can increase the AC resistance of a transformer or inductor by 10 to100 times more than Skin Effect can.

Precision's Expertise: Litz Wire – Skin Depth vs. Frequency

Figure 4: Skin Depth vs. Frequency



- ✓ Single-stranded wire can be chosen based on skin depth performance to optimize its AC/DC resistance ratio
- ✓ Goal: Reach unity condition wherein the conductor is fully utilized for carrying high frequency current without wasted non-current carrying space in the center
- ✓ Unity condition is achieved by selecting wire with 2X the diameter of the skin depth

Figure 4 demonstrates skin depth vs. frequency. Single-stranded wire can be chosen based on skin depth performance to optimize its AC/DC resistance ratio. The goal is to reach the unity condition wherein the conductor is fully utilized for carrying high frequency current without any wasted non-current carrying space in the center. It has been proven that such unity condition is achieved by selecting wire with twice the diameter of the skin depth.

Precision's Expertise: Litz Wire Figure Comparisons

Figure 5: Skin Depth vs. Single Strand Wire AWG

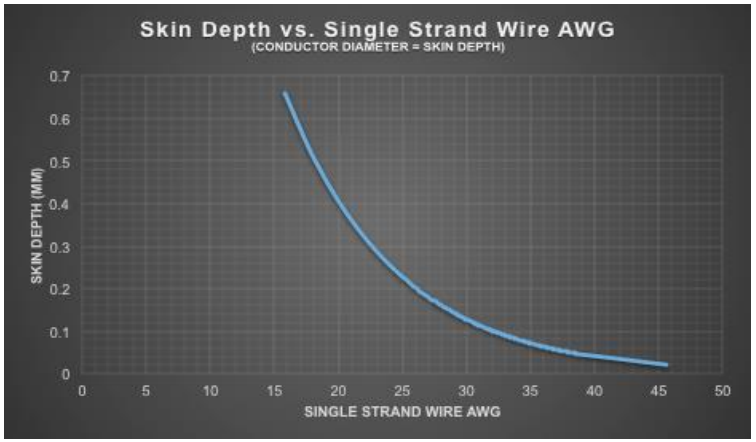
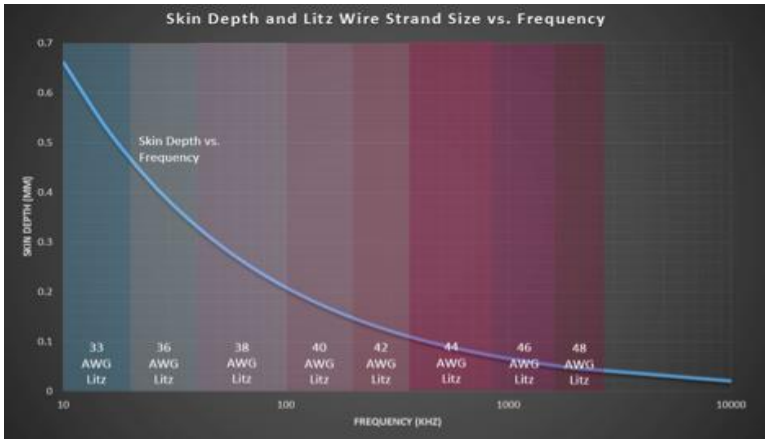


Figure 6: Skin Depth & Litz Wire Strand Sizes vs. Frequency



Comparison & Conclusion:

- ✓ Strand size in Figure 6 is significantly smaller than the single strand wire AWG in Figure 5 due to Proximity Effect
- ✓ Difference shows significance of proper Litz wire selection
- ✓ Selecting wire strand size incorrectly can be costly to your system efficiency and component temperature

Litz wire has traditionally been used to combat both Skin and Proximity Effects. It is made with a bundle of smaller strand size wire. Figure 5 shows skin depth vs. single strand wire AWG, achieving the unity AC/DC ratio. Figure 6 illustrates commonly used Litz wire strand sizes vs. switching frequency. For the same frequency, the strand size in Figure 6 is significantly smaller than the single strand wire AWG in Figure 5 due to Proximity Effect. This difference shows the significance of proper litz wire selection. Selecting wire strand size incorrectly can prove to be costly to your system efficiency and component temperature.

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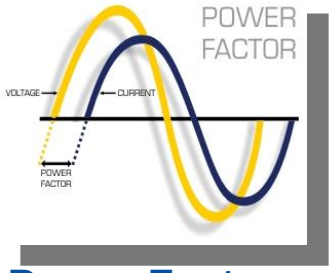
Applications:



Power Factor Correction

Servers

Solar

Industrial Motor Drives

Automotive/HEV

Power Supplies/UPS

The Precision GaN-ready LLC transformers and PFC inductors are available for a wide range of applications including power factor correction, servers, solar, industrial motor drives, automotive/HEV and power supplies/UPS .

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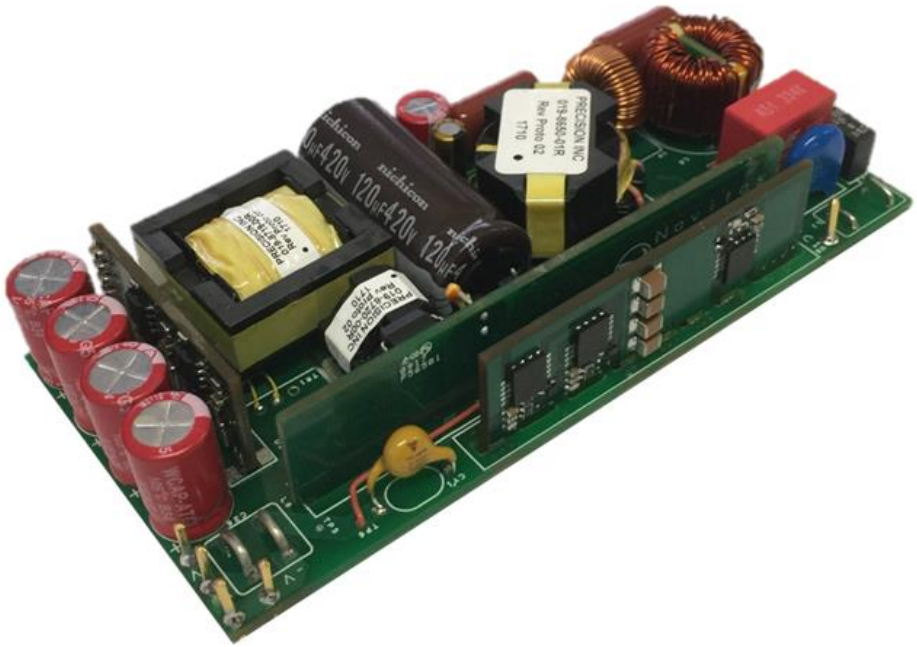
Technology Partners:

Navitas SEMICONDUCTOR

150W, AC-19V$_{DC}$ PFC+LLC Demo Board

UG016



Demo Board#	Description	Part(s) Used
NVE021A-B	150W, AC-19V (PFC+LLC)	NV6115, NV6117

This demo board uses single iDrive™ GaN Power ICs in a 150W AC-19 VDC CrCM PFC+LLC converter suitable for applications such as large laptop adapters, TV / monitor and ‘All-in-one’ PCs. With a power density of more than 21W/inches3 and efficiency of more than 95%, this demo board is more than 2x smaller than typical commercial designs and 40% smaller than the previous best-in-class.

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Technology Partners: transphorm

EZ-GaN Evaluation Board All-in-One Power Supply from Transphorm is a complete high-density 250W computer power supply using 600V GaN HEMTs switching at 200 kHz

System provides **up to a 45% reduction** in size compared to an Si-based equivalent with a highly efficient design **greater than 95%** peak efficiency

Larger systems with Precision GaN-ready components available through Transphorm. The EZ-GaN Evaluation Board All-in-One Power Supply from Transphorm is a complete high-density 250W computer power supply using 600V GaN HEMTs switching at 200 kHz. The system provides up to a 45% reduction in size compared to an Si-based equivalent with a highly efficient design greater than 95% peak efficiency.

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Technology Partners: IR International Rectifier

Circuit achieves 99% efficiency with Precision's PFC-01200-00 inductor.

Demonstrated through a bridgeless Totem-Pole PFC circuit at APEC 2014

International Rectifier's circuit achieves 99% efficiency with Precision's PFC-01200-00 inductor. International Rectifier demonstrated its GaN technologies through a bridgeless Totem-Pole PFC circuit at APEC 2014.

Thank you.

For more information please call 877-892-7107 or email customerservice@precision-inc.com