

# Optimize Power Factor Correction Inductors

The world is moving toward greater use of power factor correction (PFC). This requires attention to the components employed for power factor correction, particularly the associated inductor.

Excessive use of electricity and poor efficiencies are no longer acceptable. Eliminating poor power factor will result in increasing electrical efficiencies and will reduce the overall use of electricity. Until now, most inductors used for Power Factor Correction have been custom designed for their application, resulting in higher costs and longer lead times. Using online design tools and properly grouping circuit parameters, standard inductor products can be used to solve power factor issues.

Eliminating power factor issues can be handled in many different ways. However, not all power factor corrections work for every power factor issue. Without properly understanding what power factor is, and what affects it, can lead to even more inefficient designs.

## POWER FACTOR

Power factor is a measure of how efficiently, or inefficiently, electrical power is used. Power factor is expressed as a fraction between 0 and 1 and is the ratio between real power and apparent power.

$$\text{Power Factor} = \frac{\text{Real Power}}{\text{Apparent Power}}$$

Apparent power is a function of the total impedance (Z) of the circuit, and is the vector sum of real and reactive power. Fig. 1 shows the vector relationships.

To further define the two components of apparent power, the real power consists of circuit's dissipative elements, usually resistances (R) while reactive power consists of a circuit's reactive elements (X) (capacitors and coils). Since apparent power is the product of a circuit's voltage and current, without reference to

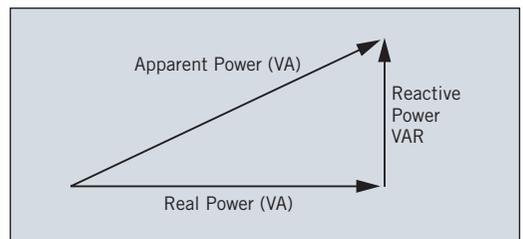


Fig. 1. Vector relationships for ac power

TABLE 1. GUIDELINES FOR MAGNETIC CORE SELECTION					
PERFORMANCE	DC BIAS (SATURATION)	AC LOSSES	LOWEST COST	SOFT SATURATION	THERMAL STABILITY
Best	High Flux	Gapped Ferrite	Gapped Ferrite	High Flux	Kool Mu
2nd Best	XFlux	MPP	Iron Powder	Kool Mu	High Flux
3rd Best	Laminated Silicon Iron	Laminated Amorphous	Kool Mu	MPP	MPP
Lowest	Laminated Amorphous	Kool Mu	XFlux	Iron Powder	

phase angle, it is measured in Volt-Amps (VA).

Power Factor is a practical measure of the efficiency of power usage in a circuit. Circuits containing purely resistive elements have a power factor of 1.0. Circuits containing inductive or capacitive elements have a power factor below 1.0. For two circuits utilizing the same amount of real power, the system with the lower power factor will have higher circulating currents due to energy that returns to the source from energy storage in the load. These higher currents produce higher losses and reduce overall efficiency. A lower power factor circuit will have a higher apparent power and higher losses for the same amount of real power.

Power factor correction adjusts the power factor in an AC power circuit closer to unity by adding an equal and opposite load to the circuit to cancel out the effects of the load's reactance. Capacitors and inductors can be added which act to cancel the inductive or capacitive effects of the load. Capacitive reactance can only be canceled by adding inductive reactance; inductive reactance can only be cancelled by adding capacitive reactance. The effect of the opposing reactances is to bring the circuit's total impedance equal to its total resistance. In other words, the real power and the apparent power match, making the power factor closer (or equal) to 1.

Another reason to resolve Power Factor issues is to comply with international regulations, especially if you intend to sell your equipment in Europe. The European Union (EU) established limits on harmonic currents that can appear on the mains (AC line) of switch-mode power supplies. EN61000-3-2 applies to power supplies with input power of 75 watts or greater, and that pull up to 16 amps off the mains. Power supplies with PFC circuits that meet EN61000-3-2 inherently have high power factors that are typically 0.97 or better.

IC manufacturers have been designing their circuitry to meet the European regulations, and are anticipating that similar regulations will be developed for other parts of the world. In the design of their circuitry, most IC manufacturers have initiated many inductor designs to meet the requirements of their circuitry. These designs have typically been "off the shelf" inductors, not intended to meet the demands of Power Factor Correction or expensive, highly custom designed inductors.

### INDUCTOR VARIATIONS

An inductor or reactor is a passive electrical component that can store energy in a magnetic field created by the electric current passing through it. An inductor's ability

to store magnetic energy is measured by its inductance, in units of henries. Typically, an inductor is a conducting wire shaped as a coil; the loops help to create a strong magnetic field inside the coil due to Ampere's Law. Due to the time-varying magnetic field inside the coil, a voltage is induced, according to Faraday's law of electromagnetic induction, which by Lenz's Law opposes the change in current that created it. Inductors are one of the basic components used in electronics where current and voltage change with time, due to the ability of inductors to delay and reshape alternating currents. Inductors called chokes are used as parts of filters in power supplies, or to block AC signals from passing through a circuit.

Almost any style of power inductor can be used for Power Factor Correction, but for this analysis, toroidal inductors are used.

Toroidal inductors offer higher performance than other types of inductors. Toroidal inductors use less volume, weigh less and emit lower electromagnetic interference (EMI). Winding heat transfer is more efficient as a proportionally larger surface area of copper is available to be cooled. The toroidal geometry leads to near complete magnetic field cancellation outside of its coil, allowing the toroidal inductor to have less electromagnetic Interference (EMI) when compared to other inductors of equal power rating. Single layer winding and a full 360 degree winding around the core make for excellent turn to turn coupling and lower leakage inductance.

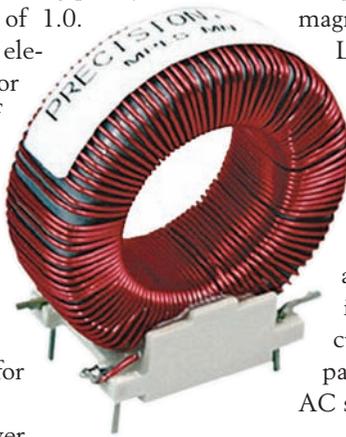


Fig. 2. Toroidal inductor with improved mounting

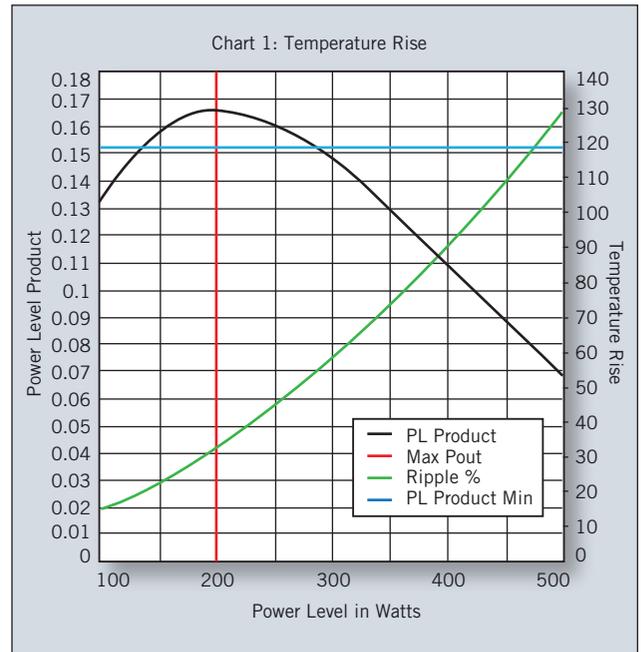


Fig. 3. PFC inductor characteristics

Toroidal inductors can be used in any inductor application that can accommodate its shape. Although usable, toroidal inductors are not always practical for some applications.

Toroidal inductor cores are available in many materials: silicon steel, nickel iron, moly-permalloy powder, iron powdered, amorphous, ferrites, and others. Silicon steel and nickel iron are available as tape wound cores or laminated pieces. Non-magnetic toroids are also available to make air core toroidal inductors. For Power Factor Correction applications, powdered iron, Kool-mu (Sendust), Hi Flux, moly-permalloy and XFlux each provide their own unique solutions to frequency, power handling and biasing needs. *Table 1* shows general “rule of thumb” guidelines and tradeoffs for material selection.

Another useful criterion for material selection is the frequency range the material is intended for. Operating frequency decisions involve tradeoffs in core & winding losses of the inductor. With wound magnetic components and commonly available core materials, a study of these tradeoffs leads to the conclusion that operation up to 300-400 kHz is possible but is a diminish in return after about 125 kHz. *Table 2* gives some general guidelines for maximum frequency ranges of several materials.

Optimally, the inductor should be small and inexpensive. However, reliability or performance of the inductor cannot be sacrificed. To avoid sudden saturation, the core will need to be of relatively low permeability to support the DC component of operation. If a gap is used in a high

TABLE 2. FREQUENCY RANGE OF MAGNETIC MATERIALS	
CORE MATERIAL	FREQUENCY RANGE
High Flux	Up to 50 kHz
MPP	Up to 200 kHz
Kool Mu	Up to 200 kHz
Powdered Iron	Up to 25 kHz
Laminated Steel	Up to 10 kHz
Gapped Ferrite	20 Hz to 2 MHz
Amorphous Strip	10 kHz to 100 kHz
XFlux	Up to 25 kHz

permeability material, consideration has to be given to where it is placed and what are its losses. These considerations argue in favor of distributed gap materials such as powdered iron, MPP, sendust, KoolMu, and against ferrite.

Mounting a toroidal inductor has become easier as the industry has standardized on carriers and landing patterns. Depending on the toroid size, it may be further secured using epoxy, mounting screws, or even tie wraps. Horizontal and vertical mounting options are available to the circuit

designer, depending on the available board (or enclosure) mounting area. For example, placing a toroid flat on the board may take up too much board area, while in some applications standing the toroid vertically will interfere with a height restriction. *Fig. 2* shows a toroidal inductor with improved mounting characteristics.

One reason PFC circuits can be difficult to design is that engineers must fully understand the PFC inductor’s operating characteristics and its effect on the PFC circuit as design criteria changes. The inductor selection is still extremely custom based upon the circuit designer’s choices of operating mode, frequency range, maximum output power, efficiency, max and min AC voltages, output voltage and ripple current. Typically, the most important factor in the final choice is size and cost, and not the most optimum. The magnetic designer must balance these requirements, even though most of these parameters move in opposite directions, working against each other. Communication between the circuit designer and the magnetic designer help to prioritize which parameter is more crucial to satisfy the design requirements.

Based upon customer demand, several companies have developed standard inductor designs specifically intended for power factor correction in power supply design. In doing so, these companies have standardized around common operation parameters. One company’s line of power factor correction inductors is based upon a CCM (continuous conduction mode) method of operation, 100 kHz operation, 92% efficiency,  $V_{IN}$  of 85-265 and  $V_{OUT}$  of 385. In standardizing the inductor, they have also streamlined the inductor selection process.

During the 2010 APEC, Welly Chou, of Precision, Inc. presented his development of the PL Product tool. Chou developed an interactive model called PL Product to be used by design engineers to evaluate and speed the selection of PFC inductors in the circuitry. Traditionally, PFC inductors are developed based on a set of circuit parameters, i.e., minimum line voltage, switching frequency, ripple current, DC output voltage, etc. While such appli-

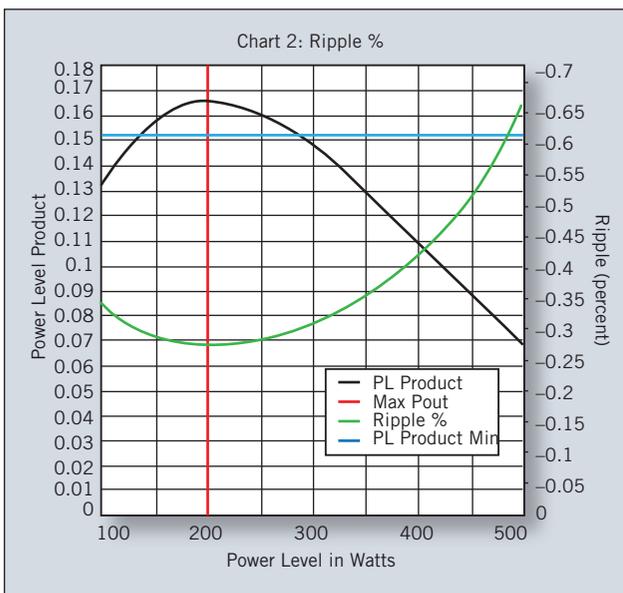


Fig. 4. Expected ripple of the selected inductor

cation specific approach optimizes the inductor design, it makes it difficult to understand the relationship and the trade-offs among the circuit parameters and the inductor. PL product simplifies this by separating the output power (P) and the Inductance (L) needed for a desired ripple current from the PFC circuit parameters, leaving designers with a simple computation to derive the minimum PL required without delving into the intricacies of the inductor. Fig. 3 shows the characteristics of the selected inductor. Anticipated ripple of the selected inductor is shown in Fig. 4.

To support Chou's PL Product calculation, Precision, Inc. has developed an online PL Product calculator (<http://pfc.precision-inc.com/>), a user-driven software used to characterize PFC inductors over a range of output power. Based on desired circuit operating parameters, designers can calculate the PL Product required for their application and correlate it to the PL Curves of various PFC inductors. This will not only simplify the design process by making inductor selection easier, but also allow circuit and PFC inductor characteristics to be realized under various operating conditions. The PL Product

makes it easier for circuit designers to understand the relationship and trade-offs among circuit parameters and the inductor.

Low Power Factor continues to be a growing issue. The European Union has already identified this situation and has developed regulations to address Power Factor Correction. As more regulations come forward, power factor correction will become needed in almost all applications. Circuit designers will continue to face difficult design choices, including cost vs. performance choices in magnetic components. Using the proper tools and industry standard inductor designs and footprints is the key to cost-effective solutions to circuit designs. Understanding the proper techniques for correcting power factor will help increase electrical efficiency. ⏻

*Many thanks to Lyle Shaw and David Anderson of Precision, Inc. and Mark Swihart of Magnetics, Inc. in support of this article.*

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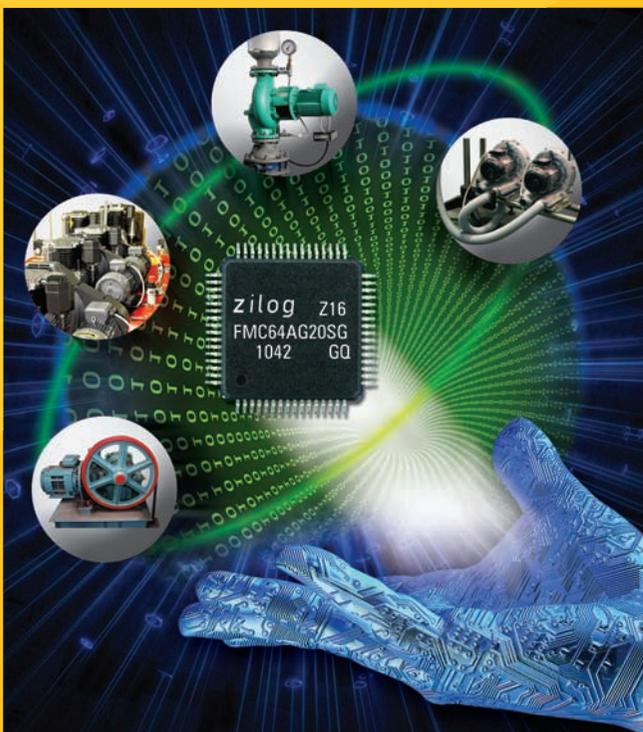
## Zilog's Z16FMC Series of Flash Microcontrollers

Zilog's Z16FMC Series of Flash microcontrollers are ideal for 3-phase and single-phase AC induction, permanent magnet synchronous motors (PMSMs), and brushless DC motor control. These motors are typically used in industrial variable frequency drives (VFDs), elevators, fans and pumps, compressors, and large appliances.

The sixteen 32-bit general-purpose registers support complex CISC addressing modes and a single-cycle instruction set that includes capabilities needed to compile compact, efficient machine code. Four channels of linked list DMA ensure the CPU is free to perform additional system level tasks while also controlling the motor.

The Z16FMC Series Development Kit includes everything you need to start working with the Z16FMC family of devices. The kit includes a development board, USB debugger, ZDS II integrated development environment and sample application software to drive a sensorless BLDC motor.

To learn more visit [www.zilog.com](http://www.zilog.com)



Part Number	Flash (KB)	RAM (KB)	I/O	Multi-Channel Timers with PWM	Standard Timers with PWM	ADC Inputs	UARTs w/ LIN/IrDA	I <sup>2</sup> C Master/Slave	ESPI
Z16FMC28	128	4	46	1	3	12	2	1	1
Z16FMC28	64	4	46	1	3	12	2	1	1
Z16FMC28	32	2	46	1	3	12	2	1	1