Technical Article

How to Design an Efficient and Cost-Competitive Choke in PFC Applications

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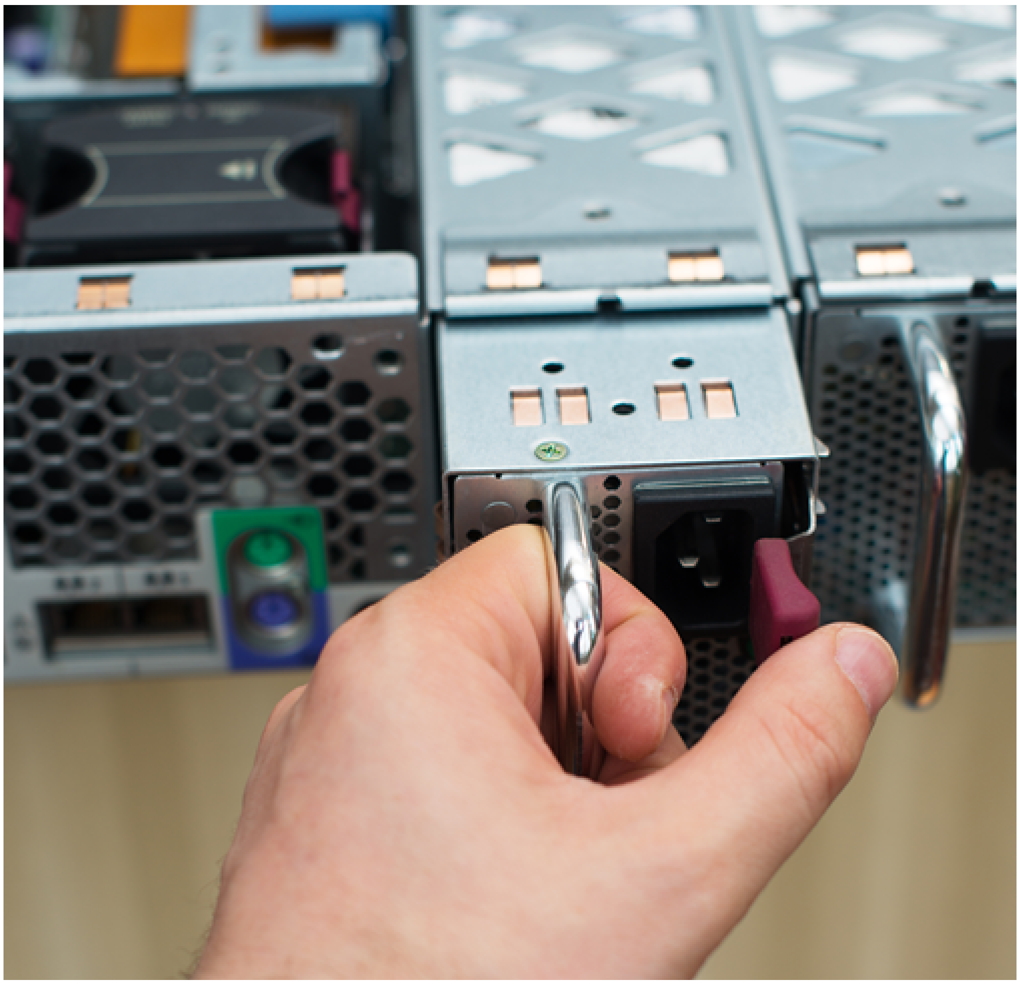
As losses in the grid increase due to bad power factor (PF), mandates call for more and more end equipment to comply with stringent target values. Air conditioners are already fully regulated, but other motorized appliances such as ceiling fans, vacuum cleaners or refrigerators will likely be next.



Power-supply unit (PSU) efficiency enhancement has been an important research goal in the development of systems that consume significant amounts of power. Because medium- and high-capacity PSUs with power ratings of hundreds of watts or more require high power-factor performance, such devices have two-stage structures that include a power factor correction (PFC) circuit.

The efficiency of the PFC power stage is important to overall PSU performance. PFC circuit performance has continually improved through the use of better switching parts (field effect transistors [FETs] and diodes), the development of improved magnetic parts materials, and the application of circuit structure research. In this post, I'll explain how to select and design an efficient and cost-competitive PFC choke to improve the efficiency of the PFC power stage.

Figure 1 shows a typical single-phase boost PFC main power stage. In this topology, four things contribute most to consumption:

- Bridge diode loss.
- Inductance loss, including core loss and copper loss.
- Freewheeling diode loss, including conduction loss and reverse-recovery loss (the latter only generated under continuous conduction mode [CCM]).
- Switching device losses, including switching loss, conduction loss and drive loss.

Figure 1 shows what parameters from the PFC stage have influence on efficiency. Next we'll discuss how to select a suitable magnetic material in a PFC choke design that improves efficiency, yet is cost competitive.

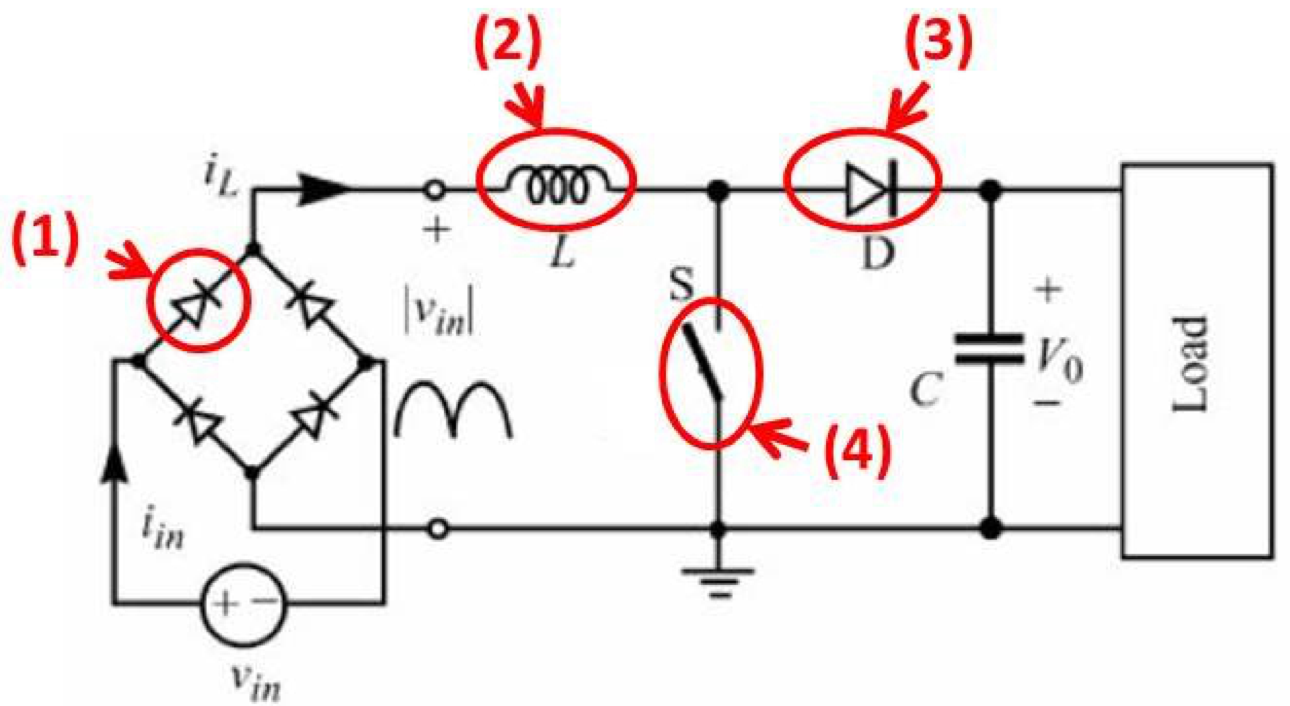


Figure 1. Typical Single-Phase Boost PFC Main Power Stage

Usually, the magnetic core is classified into alloy-type cores and ferrite cores, with the alloy-type core including iron powder cores, sendust cores, and iron-nickel alloy and amorphous cores. Different magnetic materials have different features: a ferrite core has a high micro value so you can get high inductance easily, but it is also easily saturated. An alloy-type core has soft saturation characteristics, which means that it would not be saturated even if it passed a short current, a feature very useful in some applications. Table 1 compares the different magnetic materials.

Table 1. Comparison of Different Magnetic Materials

Magnetic material	Bmax (Tesla)	Core loss	DC bias	Frequency	Cost
Sendust (KoolMu)	0.7	Low	Good	40-60kHz	Low
Iron silicon (XFlux)	1.1	Middle	Better	40-70kHz	Higher than KoolMu
High magnetic flux	1	Middle	Better	80-100kHz	Middle
Molybdenum permalloy (MPP)	0.5	Lowest	Better	80-100kHz	High
Iron powder	0.8	High	Good	20-60kHz	Lowest
Ferrite	0.3	Low	Best	100-500kHz	Low
Amorphous	0.8	Middle	Best	50k-150kHz	High
Silicon steel	1.2-1.3	High	Best	10-20kHz	High

Different magnetic core shapes have different characteristics, such as cost, thermal and shielding characteristics. Table 2 compares the key features between different shapes.

Table 2. Comparison of Key Features Between Different Shapes

	POT	RM	EE	EER	PQ	EP	Toroidal
Cost of core	High	High	Low	Middle	High	Middle	Lowest
Cost of wire frame	Low	Low	Low	Middle	High	High	–
Cost of winding	Low	Low	Low	Low	Low	Low	High
Winding difficulty	Easy	Easy	Easiest	Easiest	Easy	Easy	Difficult
Combination	Simple	Simple	Simple	Middle	Simple	Simple	–
Cooling effect	Poorest	Good	Best	Good	Good	Poorest	Good
Shielding	Best	Good	Poorest	Poorest	Good	Best	Good

When you start a new design, you should first know what your main goal is: high efficiency, low cost or small form factor. Different requirements determine which magnetic material you should choose to achieve the best performance.

The 230-V, 3.5-kW PFC with ≥98% Efficiency, Optimized for BOM and Size Reference Design is a TI design especially suitable in appliance applications like air conditioners. In this reference design, I used the sendust core as the PFC choke. I chose 45kHz as the main switching frequency, because at this frequency, a sendust core has the best balance of cost and efficiency, so I can get very high efficiency at a high line input.

Table 3 shows the efficiency test results under $230V_{AC}$ and $270V_{AC}$ inputs, respectively. Also, because sendust cores have the characteristic of soft saturation, they avoid the risk of short circuits on the main switch.

Table 3. Efficiency, PF, and THD Test Results Under a 270-V_{AC} Input

V_{INAC} (V)	I_{INAC} (A)	P_{INAC} (W)	PF	THD_i (%)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)
230.0	0.62	81.3	0.569	18.74	392.3	0.20	77.2	94.96
230.0	0.90	165.6	0.802	22.51	392.3	0.41	160.2	96.75
230.0	1.18	244.4	0.901	10.20	392.3	0.61	237.6	97.21
230.0	1.49	322.4	0.941	6.39	392.3	0.80	314.8	97.65
230.0	1.82	401.2	0.960	3.54	392.3	1.00	392.4	97.81
230.0	3.52	799.0	0.987	4.88	392.3	2.00	784.6	98.20
230.0	5.26	1198.0	0.990	4.00	392.4	3.00	1177.7	98.31
230.0	7.00	1592.0	0.989	3.65	392.5	3.99	1565.4	98.33
230.0	8.78	1994.0	0.987	3.63	392.6	4.99	1958.5	98.22
230.0	10.56	2406.9	0.991	1.67	392.6	6.02	2363.8	98.21
230.0	12.30	2808.6	0.993	1.87	392.7	7.02	2755.2	98.10
230.0	14.04	3208.3	0.994	2.21	392.7	8.01	3145.9	98.06
230.0	15.78	3612.3	0.995	2.40	392.8	9.01	3537.6	97.93

From these tables, you can see that it's possible to approach 98.6% peak efficiency at a high line input without using any expensive components like silicon carbide (SiC) diodes.

Figure 2 shows a line-frequency PFC choke current under a 230V_{AC} input; the shape is the same as the input voltage. Figure 3 shows a switching-frequency PFC choke current under a 230V_{AC} input. From this picture, you can see that there is almost no ring noise when the switch turns on and off, which helps with electromagnetic interference (EMI) performance.

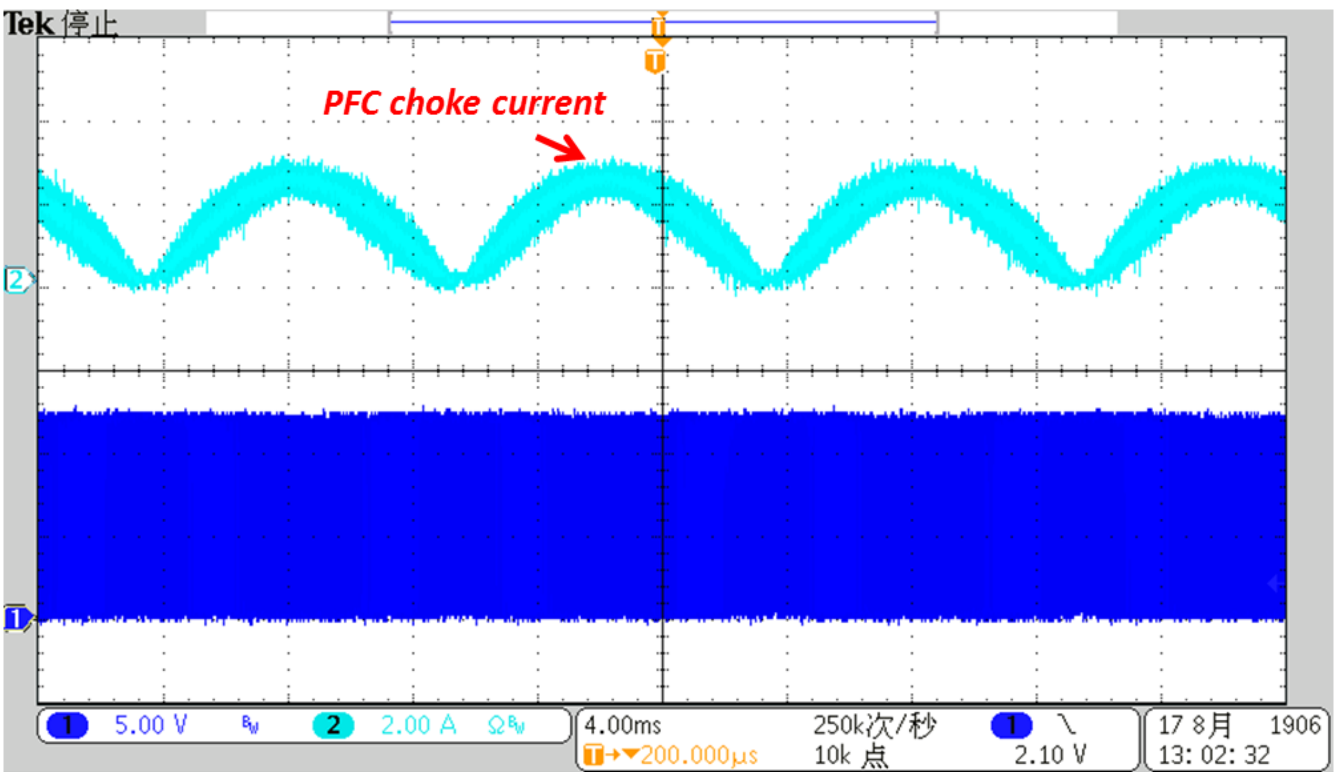


Figure 2. Line-Frequency PFC Choke Current Under a 230-V_{AC} Input

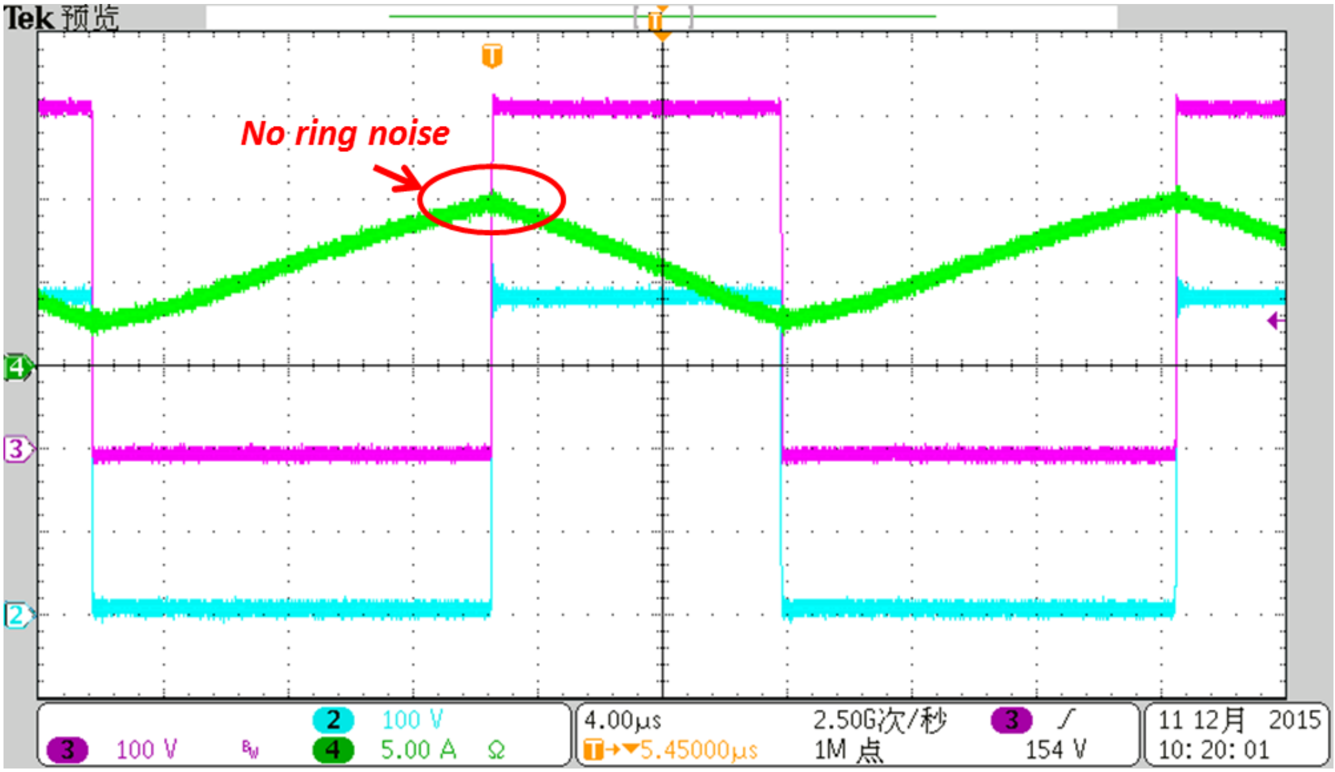


Figure 3. Switching-Frequency PFC Choke Current Under a 230-V_{AC} Input

As mentioned earlier, the increased stringent power requirements in home appliances are requiring better PFC solutions. The 230-V, 3.5-kW PFC with ≥98% Efficiency, Optimized for BOM and Size Reference Design shows designers how to build an efficient PFC stage still being optimized for cost and size.

Additional Resources

- Learn more about the UCC28180 8-pin Continuous Conduction Mode (CCM) PFC controller