

# Using the 7720-1-EVM: PFC Design Tips and Techniques



## Features:

- Bare die attach with epoxy
- Gold wire bondable
- Integral precision resistors
- Reduced size and weight
- High temperature operation
- Solder ready surfaces for flip chips

## Introduction

This BI Technologies Application Note provides an operation overview, some practical hints, design guidelines, and how to avoid potential problem areas when designing power factor correction systems in the 500 to 3000 watt power range. Written to support designs incorporating the BI Technologies' 7700 Series Power Factor Correction Modules it, nevertheless, offers useful tips for anyone designing an active power factor corrector.

Power factor correction is typically required for off line switching power supplies of greater than 500 watts. The nonsinusoidal manner in which switching supplies draw current from the power line causes two unacceptable consequences. First, the power source, circuit breakers, and wiring must all be sized larger to support the peak currents required by the reactive nature of the load that switching power supplies present to the power line. Second, the harmonics resulting from non-sinusoidal current create considerable EMI. Both of these difficulties can be overcome by using an active PFC.

Shown below, the BI Technologies 7720-1-EVM PFC Evaluation Board incorporates the BI Model 7720-1A PFC Module. This Module contains the input bridge rectifier, the power switching FET, ultra fast diode and overtemperature sensor; all the critical power components necessary for an efficient and compact PFC design. The BI 7720 is easy to mount to a heatsink, and is engineered for superior heat transfer. The board also holds the power inductor, output capacitor, current sense resistor, and the required control and thermal overload circuitry to form a functioning PFC to assist customers in speeding the development of their own PFC.

## Principle of Operation

Basically, all a successful PFC design has to do is force the input current to follow the input line voltage regardless of what the load current (the switching power supply) is doing. If the input current is sinusoidal then the harmonic and peak current problems are solved, and if the input current is in phase with the input voltage a unity power factor will be achieved. Note that the line voltage is tacitly assumed to remain sinusoidal. This will only be true if the source impedance of the power line is sufficiently low. Active PFCs can achieve .999 power factors with less than 3% total harmonic distortion.

While there are other topologies, the most common boost type will be discussed here. At first glance, the circuit appears to be just a step up boost voltage regulator. While indeed regulating its output voltage, an active PFC also modulates the current through the inductor to force the input current to be sinusoidal. It



The 7720-1-EVM Evaluation Board is a working example of a complete PFC front end for power supplies from 500watts to 2500 watts. The circuit is based on BI's 7720-1A power module, which contains all of the power semiconductors for this application. It is attached on the underside of the evaluation board.

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accomplishes this by using the input voltage as a sinewave current reference signal. This reference is compared to the actual input current (determined by a current sense resistor or transformer) in order to generate an error signal. This error signal is 'processed and combined' with the output voltage error signal and a voltage feed forward signal to form the control input to a pulse width modulator (PWM). The PWM then drives the active switch, usually a power FET or IGBT, thus closing the control loop in order to create the desired sinusoidal input current.

There are really two control loops, voltage and current, plus an open loop voltage feed forward signal. The trick to an effective design rests with properly compensating these control loops, and the feed forward signal. The design details are best left to the application note for the specific control IC being employed, but the basic idea is that the current control loop must respond fast enough to modify the current into a sinusoid during the input cycle of 60 Hz. Typically, bandwidth is around 10kHz for a 100 kHz switching frequency.

However, the voltage control bandwidth must be low otherwise output regulation would be so rapid within a power line cycle that the input current would be completely distorted. Consequently, the voltage loop bandwidth is set to several power line cycles, around 20 Hz. That is, the slower the voltage loop response the lower the input current distortion, but the poorer the output voltage transient response becomes. Thus, for a given distortion the output capacitor must be increased in value until a satisfactory output voltage transient response is obtained.

To understand the 'processing and combining' of signals by the control IC, think in terms of power control, not voltage or current. Properly functioning, a PFC's instantaneous real input to real output power must remain constant (unity at 100% efficiency) despite variations in input voltage. For example, if the input voltage doubles the current must be halved if the power is to remain the same. The control IC accomplishes this by taking the input voltage and dividing by the feed forward voltage squared. The feed forward voltage is just the average (filtered) input voltage. Therefore, twice the input voltage divided by four times the input (feed forward voltage squared) results in one half the current programming, as desired. That is,  $2V_i / (2V_i \text{ avg})^2 = 1/2$ . Note the assumption that the voltage error signal remains constant during a single line cycle. This is a reasonable assumption since the voltage loop responds slowly (20 Hz).

## Using the 7720-1-EVM

Using your 7720-1-EVM is easy. Simply follow these three steps to operate your demonstration board

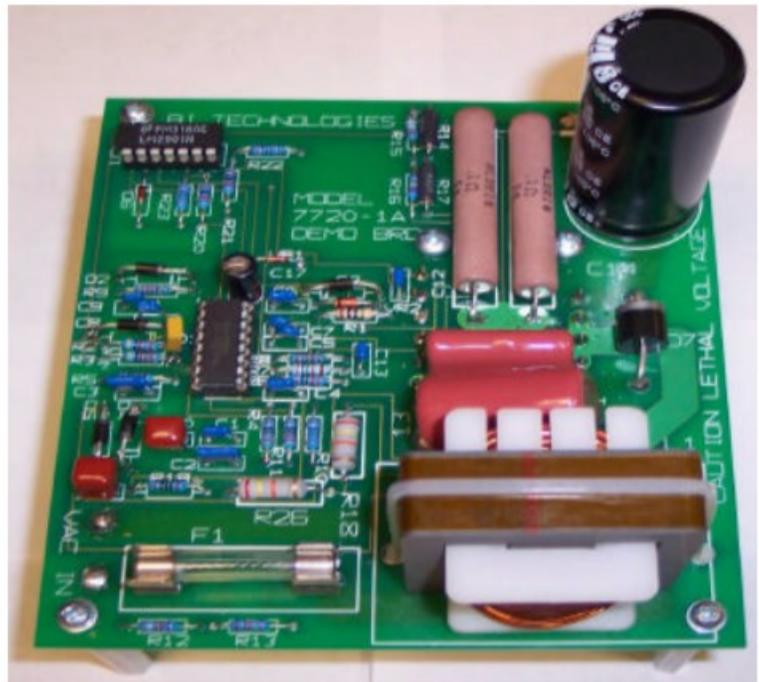
### 1. Apply load

For your initial check out, use a fixed power resistor as your load. Start with a light load until operation is established.

- Use the nominal output of 385 Volts to calculate your load resistor.
- The load should be between 100 Watts (min) and 2500 Watts (max).
- 100 Watts: 1.5 K ohm resistor
- 2500 Watts: 59 ohm resistor
- Ensure the load resistor meets the wattage and voltage requirement.
- Solder attach the load using sufficient gauge wire to the "OUTPUT" pads.

### 2. Add cooling fan

While your demo board is equipped with a heat sink on the power module, any load over 300 Watts will require forced cooling on the heat sink for continuous operation. A muffin fan appropriately



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placed should suffice. However, the 7720-1-EVM safely shuts down in the case of thermal overload. Be aware that your test load will get very hot, and may require cooling as well!

### 3. Apply AC line voltage

Attach a line and plug to the “VAC IN” pads of your board. To apply voltages other than your line voltage (85VAC to 265VAC), use a Variac. A power switch should be contained in your line.

Apply your line voltage and check for 385 VDC nominal at the output load. You are now ready to replace the load with your DC/DC circuitry or other device.

While the 7720-1-EVM board contains all the basic front end PFC functions, you will want to optimize your own design for your application. Your implementation should address your specific power level, switching frequency, and ripple level requirements. It should also include the in-rush limiting and EMI suppression as appropriate. Design guides for some of these variables follow. BI's PFC Power Module will serve the building block for your PFC design.

### Power Stage & Drive

Efficiency can be optimized by attention to several details. Switching losses can be minimized by choosing not only a fast power switch (FET or IGBT), but by using the lowest gate drive resistor possible consistent with the current capabilities of the drive circuit. Ensure that the drive circuit has sufficient local capacitance to provide the needed current. To achieve the fastest switching times requires the use of a separate driver, as the control IC will not be capable of sufficient drive current. Selecting the fastest diode possible will also improve efficiency, but at increased cost; a compromise in diode speed maybe required to meet cost targets. Be aware that lot to lot variations in the switching speed of high-speed diodes do occur, and can result in unexpected thermal failures. Utilizing an all-in-one solution, such as BI Technologies 7720 Series of PFC Modules, automatically provides all power components (input bridge rectifier, power switching FET, output diode) optimally matched for maximum efficiency, and screened for device consistency. All supplied in a small, easy to mount, thermally engineered package.

### Current Sense

The current sense signal can be accomplished with a low ohm resistor, or with a current sense transformer. Current sense resistors are an easy solution, but must be optimized for minimal power dissipation and maximum signal. Choosing current sensing transformers over sense resistors is another way to improve efficiency at the current levels found in kilowatt level PFCs. An added benefit is a marked improvement in signal to noise ratio, resulting in superior circuit operation. Winding the inductor with the largest wire will reduce dc winding loss, further improving efficiency.

### Inductor Design

Proper design of the inductor is key to long term reliability in a PFC. The iron powder cores typically used in a PFC suffer from thermal aging in the core if operated at too high a temperature. The circuit will function properly for several hundred to several thousand hours whereupon it will fail rapidly. Be very careful when core losses exceed copper losses, or when a fan must be used; it is very easy for internal core temperatures to exceed maximum ratings. It is preferable to drop to a lower permeability core material that provides lower core losses, even though winding losses will increase due to the increased turns required. Remember, worst case winding loss occurs at the lowest input voltage (highest current), while the worst case core loss occurs when the peak input voltage is equal to 0.61 times the output voltage.

### Noise/EMI

There are two types of noise problems to contend with: Conducted and radiated EMI to the outside world, and self-interference from the circuit. The first issue will not be discussed here as it is as much a system problem as a PFC design problem and is normally addressed with power line filters and proper shielding. The rapid switching of voltages and currents in a multi-kilowatt PFC can result in crippling interference to the circuit itself. Perform a careful layout to minimize the

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proximity of control circuitry to high current paths, minimize high current loop areas, and use generous ground planes. Be certain not to share low and high current ground paths! A small ( $\mu\text{F}$  range) capacitor may be required between the current amp input and multiplier output pins of the control IC. When utilizing the BI Technologies 7720 Series PFC Module's overtemperature sensor it is a good idea to place a  $0.1\mu\text{F}$  capacitor across pins 7 to 8. This will minimize noise pickup and prevent false overtemperature sensing by the control IC. To prevent latch-up difficulties, Schottky diode clamps to ground may be required on certain control IC pins. Placing Zener diode clamps on  $V_{cc}$  and the gate drive output pins of the control IC will help prevent over voltage damage from occurring.

## In-Rush Limiting

Startup current on high power PFC's can be excessive due to the low resistance path from input to the large output capacitors typically used. For this reason it is necessary to limit input current during startup. There are several methods commonly employed. For lower power levels an NTC thermistor in series with the input may prove satisfactory. At higher power an in-rush current limit resistor shunted by a relay can be used. After the PFC starts up the relay contacts are closed bypassing the resistor. Another technique is to utilize SCRs in two legs of the input bridge. The turn on angle is then controlled to limit current until the PFC is up and running. BI Technologies Model 7700 integrates an SCR bridge, power FET, ultra fast diode, and thermal sensing in a compact module.

## Safety

The 400 Volts present in a PFC is lethal. Extreme care must be exercised when operating and troubleshooting PFC circuitry. The non-isolated nature of a PFC makes it especially dangerous; an isolation transformer should be utilized if at all possible. Keeping one hand in your pocket is a wise idea as well. Be careful that the large output capacitor is discharged after power is removed. At the power levels involved, burning oneself on the power components is also a risk to be aware of.

Further, with the non-isolated bridge input on PFCs it is exceedingly easy to end up creating a short circuit with oscilloscope and test equipment grounds. Using an isolation transformer helps this potential problem as well.

## BI Technologies PFC Modules

MODEL	POWER CAPABILITY*	INPUT BRIDGE
7720-1A	1500 W/3000 W	Diode 25A
7720-2A	1000 W/2250 W	Diode 25A
7720-3A	500 W/1500 W	Diode 18A
7700-2A	2000 W/4000 W	SCR 35A
7700B	1500 W/3000 W	SCR 20A

\*Note: Power capability is at 120V/240V line voltage, respectively.

## References

BI Technologies Corp Model 7720 Series Power Factor Correction Module Data Sheet February 1998

BI Technologies Corp BI Technologies Data Book 4th Edition pp. 7-19 to 7-30, 7-41 to 7-47

Micrometals Corp. Power Conversion & Line Filter Applications Issue K, February 2003, pp. 3, 29-30, 58-59

Texas Instruments Corp. UCC2817, UCC2818, UCC3817, UCC3818 BiCMOS Power Factor Preregulator Data Sheet February 200 – Revised December 2001

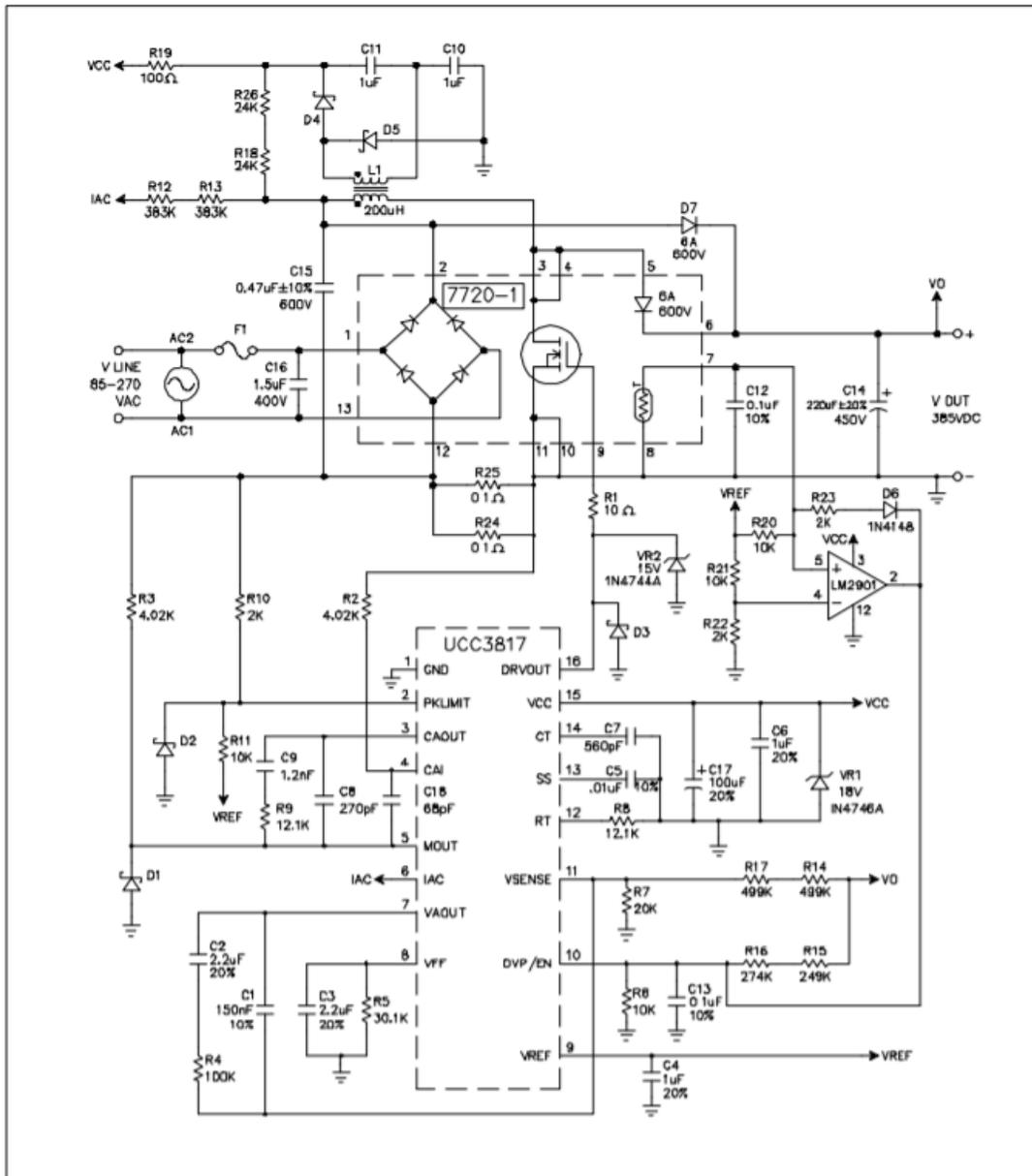
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7720-1-EVM Schematic

**PFC Module:** BI Technologies: 7720-1A (see table on page 4 for alternates)

**L1:** BI Technologies: Primary 68 Turns, #16; Secondary 4 Turns, #22;  
Core: MicroMetals E168-2; Bobbin: MicroMetals PB168

**Control IC:** Texas Instruments: UCC3817

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