

Introduction

These course notes are to be read in association with the [PI University](#) video course, [Bringing Up a Flyback Supply for the First Time](#). This course will take you through the procedures to follow for safely bringing up and testing your power supply prototype, and will ensure that the power supply is functioning properly.

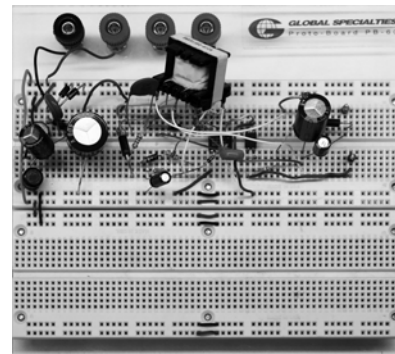
Before Starting This Course

Before beginning, please note that a number of important skills and techniques used in this course are taught in other [PI University](#) courses, as noted in the Course Prerequisites. The testing described will take approximately one to two hours to complete, so be prepared to set aside the appropriate amount of time.

Before attempting to bring up your design for the first time, ensure that it is constructed on a printed circuit board that follows the layout guidelines specified in the Power Integrations device datasheet. Constructing your design on a breadboard or proto-board will introduce many parasitic elements into the circuit that may prevent proper operation. Moreover, many breadboards are not designed to carry the current levels generated by a switching power supply and may be damaged. It is also extremely difficult to control creepage and clearance distances on these platforms.



Printed circuit board designed to layout guidelines



Breadboards will not work with switching power supplies

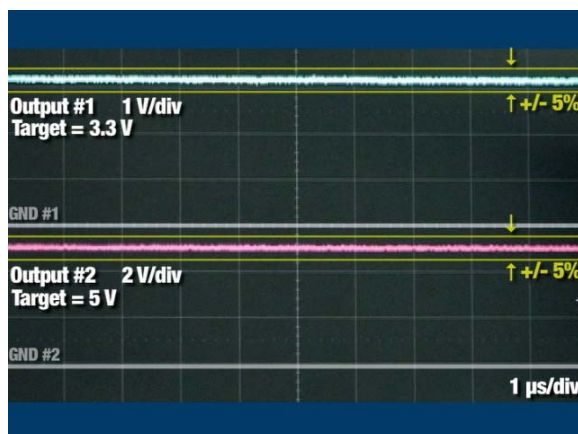
Equipment Required

The following equipment is needed for completion of this course:

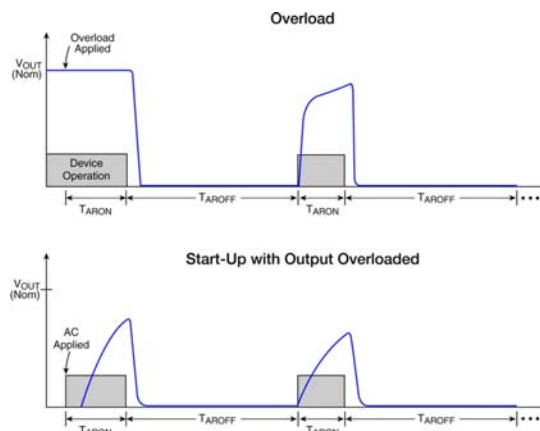
1. An isolated AC source or Variac
2. A wattmeter
3. At least four digital multimeters, with two of the four having a high resolution current range
4. An oscilloscope, with a high voltage probe
5. A current probe
6. An electronic load
7. And your actual load

Chapter 1: Terminology

Two terms will be used often during this course: regulation and auto-restart. When a power supply is in **regulation**, the controller is receiving feedback and all output voltages are stable, constant, and within specified tolerance limits. **Auto-restart** refers to a protection mode built into Power Integrations' devices.



Outputs in regulation



Auto-restart

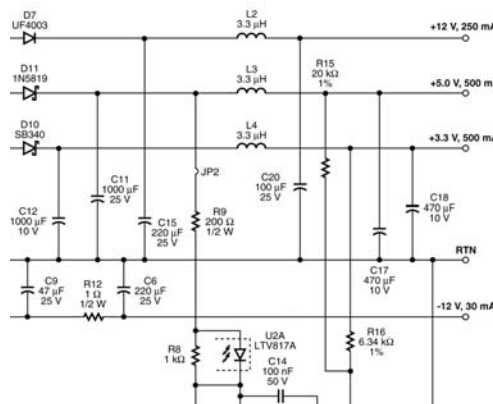
During operation, if you draw more power from your supply than it was designed to deliver, or, if at startup, the output voltage does not reach regulation within a specified time, the Power Integrations device will enter auto-restart protection mode. This will prevent components from being damaged by limiting the average power delivered by the supply in a fault condition. The specific auto-restart on-time can be found in the relevant Power Integrations device datasheet.

While testing, if the power supply does not behave as described in this course, or if it exhibits any abnormal characteristics, please stop the procedure and refer to other [PI University](#) troubleshooting courses or contact your local PI representative to resolve the problem.

Chapter 2: Design Information

Now you are ready to begin testing. As a working example, an RD-115¹ reference design board that uses a [TinySwitch -PK](#) device will be used. This supply is designed for DVD players and delivers 7.5 W continuous, 13 W peak. Continuous power is distributed across four outputs, including:

- 3.3 V at 500 mA
- 5 V at 500 mA
- Positive 12 V at 250 mA
- Negative 12 V at 30 mA



RD-115 outputs

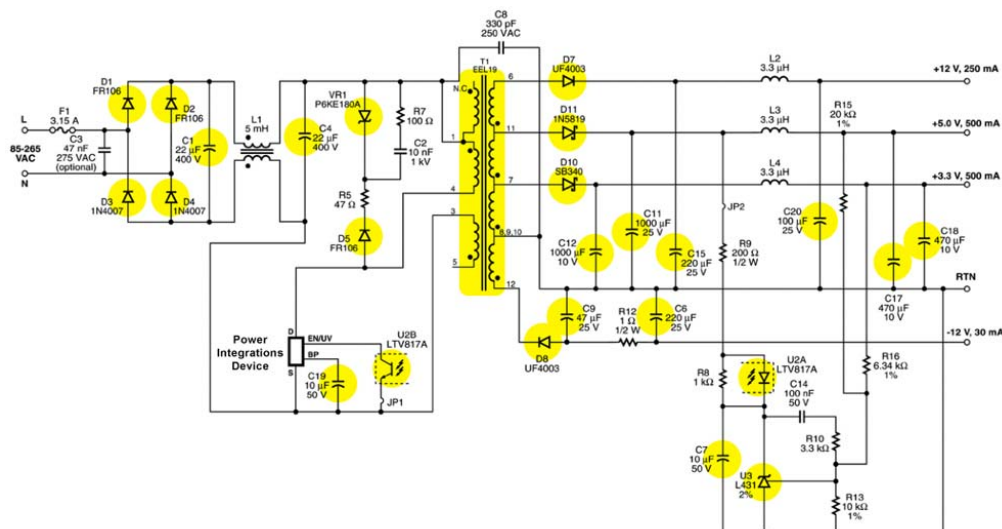
¹ [RDR-115](#): Reference Design Report for a 7.5 W Continuous, 13 W Peak DVD / Set Top Box Using TNY376PN.

Detailed design information and test results for this board can be found on the [Power Integrations website](#). For the purposes of this course, we will focus more on procedure than the actual readings obtained while bringing up this design.

Chapter 3: Visual Inspection

Begin the bring-up process by first visually inspecting the board to ensure that all polarized components have been properly inserted. Although unusual, an incorrectly-inserted component can cause a destructive failure.

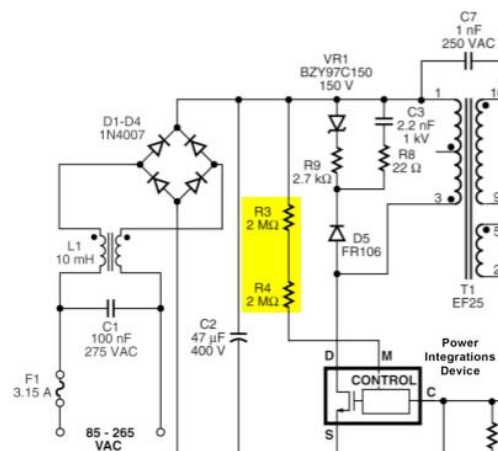
Even after checking component insertion, vision protection is highly recommended when first bringing up a power supply.



Ensure all polarized components are correctly inserted

Chapter 4: Disable Undervoltage

The first step is to check for correct operation at low input voltage, so you will need to disable the undervoltage lockout feature of the Power Integrations device, if it is enabled. In most designs, this means removing the UV resistors from the board. In this design example, the UV resistors are connected between the DC bus and M Pin of the [TOPSwitch -HX](#) device. You will need to remove these resistors and short the M Pin to source. For other products, refer to the device datasheet to identify the correct components and method for disabling the UV function.



UV resistors

Chapter 5: Very Low-Voltage Operation

Next, solder two short leads to the negative and positive terminals of the input capacitor to act as test points. To properly confirm low-voltage operation, you will need to monitor the output voltage and DC bus voltage across the input capacitor while applying a low AC input voltage. Connect a multimeter across the output terminals of the board, and another across the input capacitor, using the two test points. Both meters should be set to read DC voltage.

If your design has multiple outputs, connect load resistors to any outputs other than the main regulated output. The load resistors should be sized to draw the minimum load specified for each output. This prevents these output voltages from rising outside of specification due to peak charging.

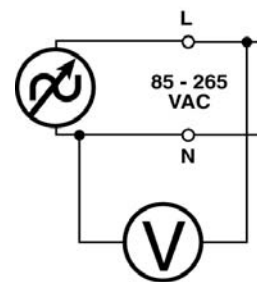
If no minimum load is specified for an output, then select the resistor to draw an output current of 5 mA. Connect the AC input leads to the board. Be sure the AC input is correctly connected to the power supply input terminals and not the DC output. Improperly connecting the AC input can severely damage your supply.

You will also need to measure AC input power for this test. If you have a wattmeter, refer to its operator's manual for instructions on how to install it in your AC input path, and configure it to measure AC voltage, current, and input power. If no wattmeter is available, connect a third multimeter in series with the AC input, set to measure AC current, and a fourth across the power supply input terminals to measure AC voltage.

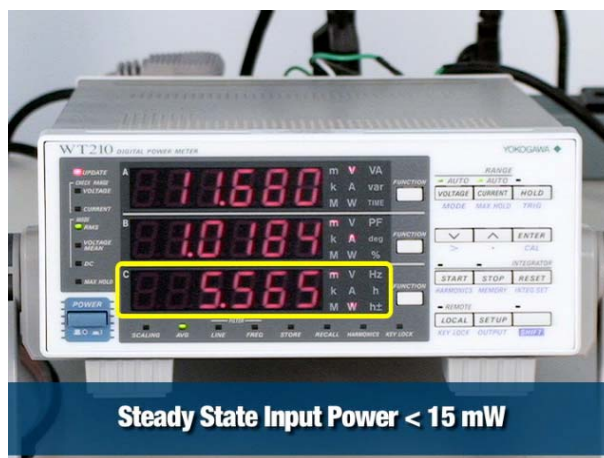
Detailed instructions on the use of wattmeters and multimeters may be found in the [PI University](#) course, [Techniques for Measuring Efficiency](#).

Now, make sure the Variac or AC source is set to zero and turn it on. Slowly increase the input voltage to about 10 VAC. You should see the AC input voltage increasing on either the wattmeter or the input multimeter. If not, confirm that your AC source is properly configured. You should also see the voltage on the DC bus increase as you apply the AC voltage.

If you are using a wattmeter, the steady-state AC input power should be less than 15 mW. If you are using two multimeters instead, the steady-state AC current should read less than 10 mA. If you see an input power or AC current higher than this, then there is a fault on your board. Turn off the AC source and disconnect the AC input.



Monitor AC input voltage, along with output and DC bus



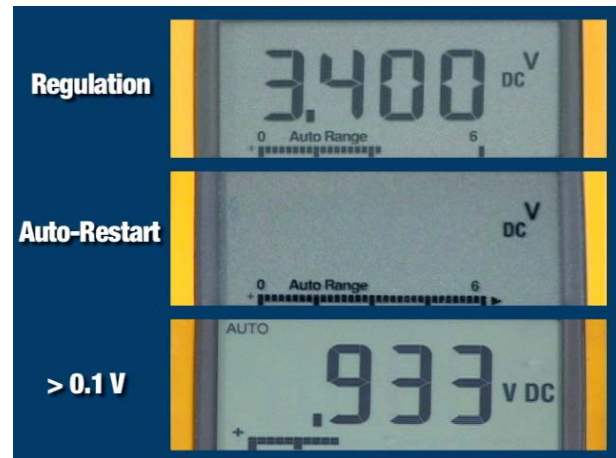
Use a wattmeter to measure input power

Continuing to increase the AC voltage under these conditions may cause a destructive failure on your board. For information on identifying and fixing the fault on your board, see the PI University course, [Fixing a Flyback Supply with No Output Voltage](#).

Chapter 6: Startup and Regulation

If the input power is less than 15 mW, then continue to increase the voltage to 50 VAC. Looking at the DC output voltage, if the output is in regulation, is in auto-restart, or the voltage on the output meter is greater than 0.1 V, then the chip is not damaged and is functioning normally.

Continue increasing the AC input voltage to the specified minimum input voltage. If the power supply does not startup or reach regulation, stop testing and see the PI University course, [Fixing a Flyback Supply Where the Output Fails to Reach Regulation](#).

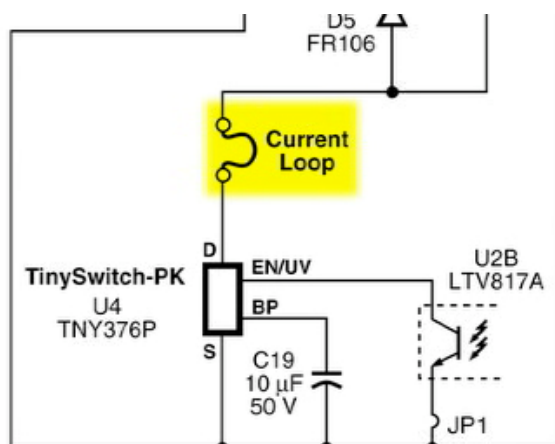


The three modes of correct operation at 50 VAC

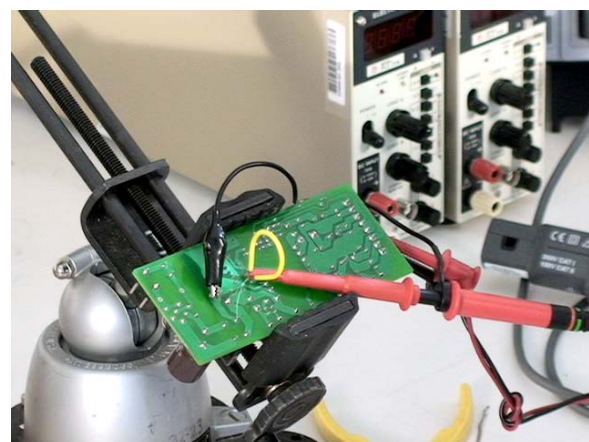
Now turn off the AC input, disconnect the input leads from the board, and discharge the input capacitor to a safe voltage level. Also, disconnect the multimeter from the DC bulk capacitor.

Chapter 7: MOSFET Drain Switching Waveforms

Next, you will need to monitor the drain switching waveforms. Break the drain trace on your board and insert a current loop. Be sure to make this break between the Drain pin of the Power Integrations device and any components in the clamp circuit. This will ensure that only the MOSFET current is viewed by the probe.



Correct positioning of current loop



Connecting the voltage probe to the MOSFET drain

Connect a 1000 V or greater x100 probe across the MOSFET to measure switching voltage. Configure your scope to view both voltage and current waveforms at an appropriate scale, and set a wide timebase so that many switching cycles can be viewed in a single frame. For example, with this 132 kHz design, the timebase is set to 50 μ s per division.

Chapter 8: Loading Primary Output

Now connect an electronic load to the primary output of your supply, making sure that the loading is set to zero. Connect two multimeters to the output, one across the output terminals to measure output voltage, and the other in series with the electronic load to measure output current. Use the highest resolution meter available to measure the output current.

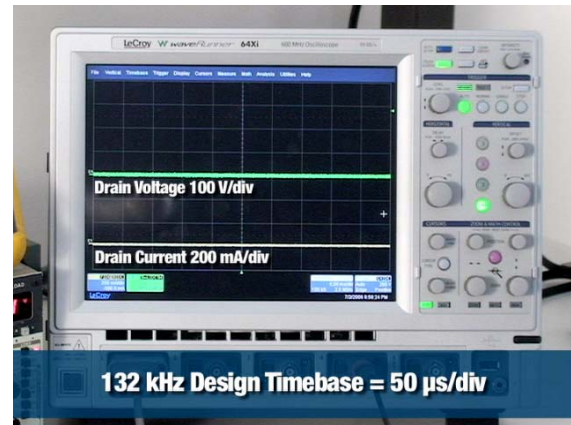
Reconnect the AC input leads to the board, and make sure the Variac or AC source is zeroed. Now, turn on the AC input, and slowly increase the voltage to the minimum specified input voltage of the design. Slowly increase the load on the power supply up to 25% of full power. The output voltage should remain within specified regulation tolerances. Continue increasing the load to full load. The output voltage should remain stable and within regulation limits.

Chapter 9: Full-Load Operation

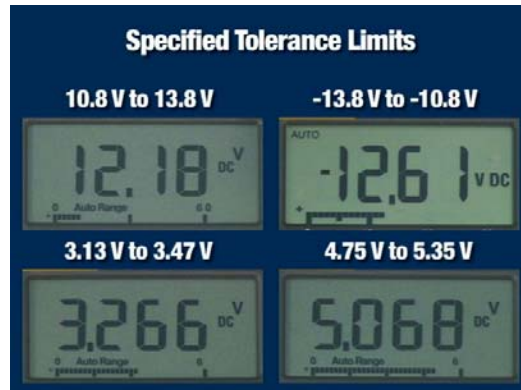
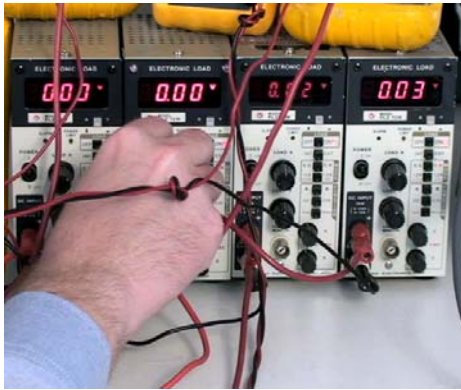
If your design includes multiple outputs, turn off the AC input and remove the minimum load resistors you installed earlier. Replace each of these resistors with an electronic load until all outputs of your design are loaded. If electronic loads are not available in your setup, please consult a power electronics introduction course for more loading options and information on how to substitute them.

Connect two multimeters to monitor output voltage and current for each output, as demonstrated earlier. For this design, with a total of 4 outputs, this requires a total of 8 multimeters, with at least 4 having a high resolution current range. This type of setup is convenient for making quick measurements. If this many meters are not available in your setup, you can use a single meter to measure all voltages by rotating it through all outputs, measuring voltages one at a time.

Set all loads to draw a small amount of current from each output to prevent peak charging. Again zero the AC input, turn it on, and slowly increase the input to the minimum operating voltage for your design. Beginning with the primary output, slowly increase the loading on each output, one at a time, up to the full rated load for that output. Continue until all outputs of the power supply are providing full specified output power.



Configuring the scope



Set all electronic loads to draw a small amount of current

All outputs must be within specified regulation limits

Your power supply is now operating at the maximum continuous output power. All outputs should be stable and within the specified tolerance limits. If they are not, then stop testing and see the [PI University](#) troubleshooting curriculum to debug the problem. If the supply has entered auto-restart, see the PI University course, [Fixing a Flyback Supply that Does Not Deliver Full Power](#).

Chapter 10: Efficiency Check

While the power supply is running at maximum continuous load and low line, perform a quick efficiency measurement and compare it against the target specified by [PI Expert](#). If you find the efficiency is lower than expected by more than 5%, then see the [PI University](#) troubleshooting curriculum to debug this issue before continuing.

Chapter 11: Peak Drain Voltage (high line)

Next, decrease the timebase on the scope and trigger on the rising edge of the drain voltage. Set the scope to normal trigger mode, and slowly increase the trigger level until the scope triggers occasionally on the highest peak seen in the MOSFET voltage.

Using scope cursors, measure the maximum voltage seen across the MOSFET at this peak. Now slowly increase the AC input voltage to maximum line voltage, pausing in 50-volt increments to increase the trigger level and measure the highest peak.

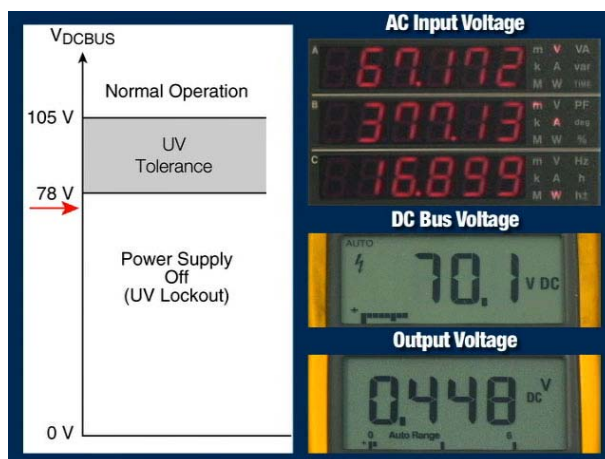
If at any time the peak drain voltage measured is greater than 650 VDC, stop increasing the input voltage to avoid exceeding the MOSFET maximum voltage rating. If you do not reach maximum line voltage before you are forced to stop, then either your clamp is improperly designed or your transformer has higher leakage inductance than expected. Resolve this issue before continuing.

Chapter 12: Undervoltage Lockout

Next, reduce the load on each output to minimum load and turn off the AC input. Reconnect the UV sense circuit, if it is included in your design. Also, connect a multimeter across the input bulk capacitor, set to measure DC voltage. Zero the AC input, turn it on, and slowly increase the voltage until the DC bus voltage reaches the lower range of the UV threshold.

The power supply should startup at a voltage that is between the two limits defined by the tolerances of the Power Integrations device and your UV resistors. It should also startup before you reach the minimum AC input voltage for the design.

In our design example, the power supply should startup between the range of 78 V and 105 VDC on the DC bus, defined by the tolerances of the resistor(s) and device UV current threshold.



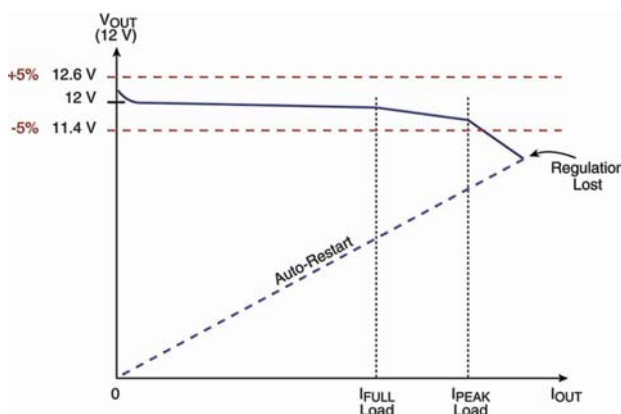
Check the voltage at which the power supply starts up

Chapter 13: Peak Drain Voltage (overload)

After the power supply starts up, increase the AC voltage to the minimum input voltage, and load the supply to full load. On the primary output, slowly begin increasing the load while monitoring the peak drain voltage on the scope. As you begin overloading the power supply output, verify that this peak voltage never exceeds 650 V. If it does, stop the test and debug your clamp circuit.

Once the maximum overload power has been reached, the output will fall out of regulation. This will either trigger the Power Integrations device to enter auto-restart or latching shutdown.

Auto-restart is the most common response to a loss in regulation, but response varies by device family and circuit configuration. Details can be found in the product datasheet.

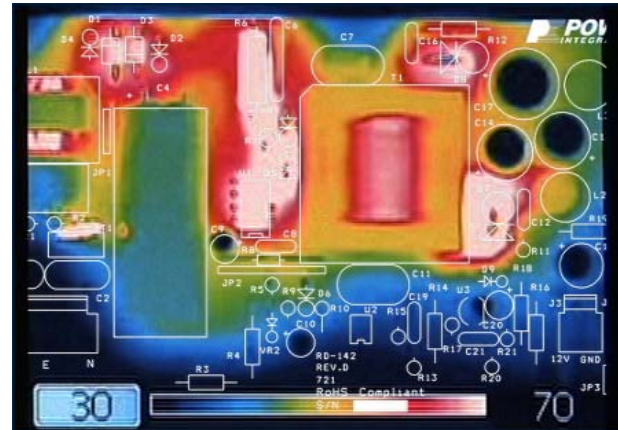


Overloading causes loss of regulation

On the scope, capture the peak drain voltage seen just before the power supply enters a protection mode. If this voltage is greater than 650 VDC, then you will need to adjust your clamp circuit.

Overloading your power supply places stress on all components and increases the dissipation in your design. This can cause components to heat up rapidly, so if you notice signs of overheating, stop the test immediately and allow time for your design to cool down.

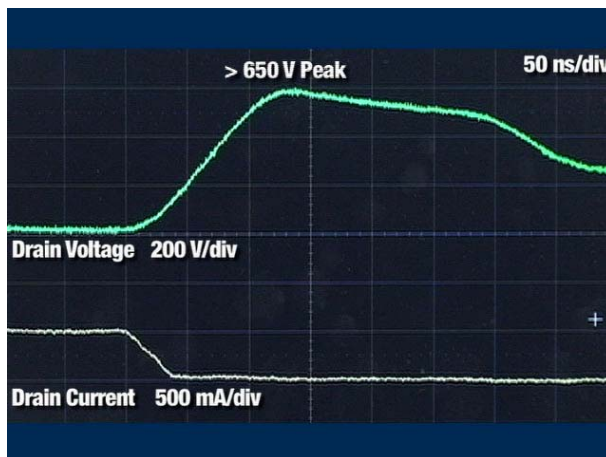
Now repeat this test at the maximum AC input voltage.



Thermal image of overloaded power supply

Chapter 14: Peak Drain Voltage (startup)

For the next test, reduce the load on the supply back to full load. If your power supply has entered latching shutdown, it may be necessary to cycle the AC input before the supply will return to normal operation. Switch off the AC source, and wait until the voltage on the DC bus has dropped to about 10 V. If a large value bulk capacitor is used in your design, this may take several minutes. The process can be accelerated using your capacitor discharge board.



Peak drain voltage at startup

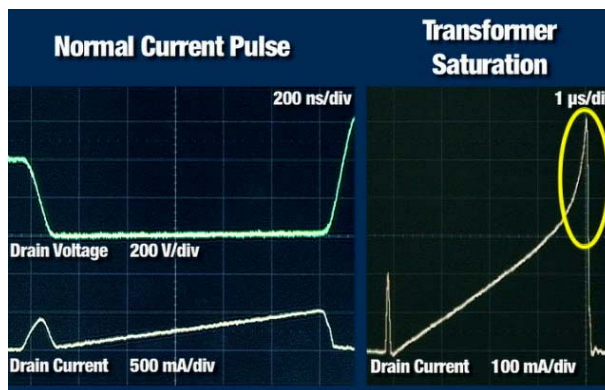
Now you will examine the drain voltage and current waveforms at startup. Increase the input voltage to the maximum value and make sure the supply is at full load. Set the scope to normal trigger on the rising edge of the drain voltage waveform. Increase the trigger level until you find the highest level that will trigger during normal operation. Then, turn off the AC and snap it back on.

Continue doing this while increasing the trigger level until you capture the highest peak voltage seen during a snap-on event. If the highest voltage measured exceeds 650 V peak, then you may need to redesign your clamp.

Chapter 15: Drain Current Shape (startup)

Repeat this procedure while triggering the scope on the drain current waveform, and measure the highest current seen during a snap-on event. Examine the shape of the current waveform for signs of transformer saturation.

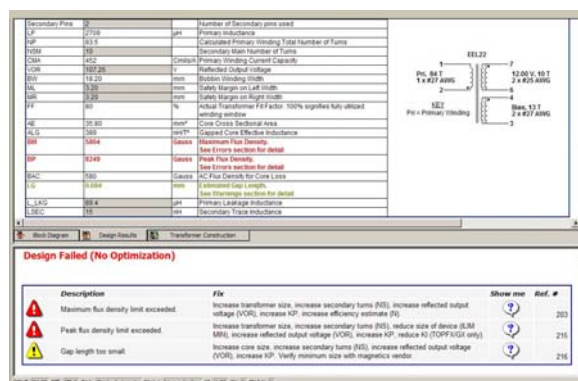
During startup, you may see one of these two current waveforms. The waveform on the left is a normal current pulse that ramps linearly from turn-on to turn-off. The current pulse on the right shows signs of transformer saturation. Notice how this pulse becomes somewhat exponential towards the higher end. This is where the transformer core saturates and can no longer store energy. At this point, primary currents can increase rapidly and may damage the Power Integrations device or other primary-side components.



Check for signs of transformer saturation

The primary cause of transformer saturation is the buildup of too much flux in the core. If you see saturation in your design, first verify with your transformer vendor that the unit was constructed exactly as specified by your [PI Expert](#) design. Also confirm that your transformer primary inductance value is within the tolerance limits allowed for your design. (See Chapter 16 for more information on how to make this measurement without an LCR meter.) Transformer saturation may also occur if the device current limit is programmed too high. Check the datasheet for the device you are using for information on how to verify current limit programming.

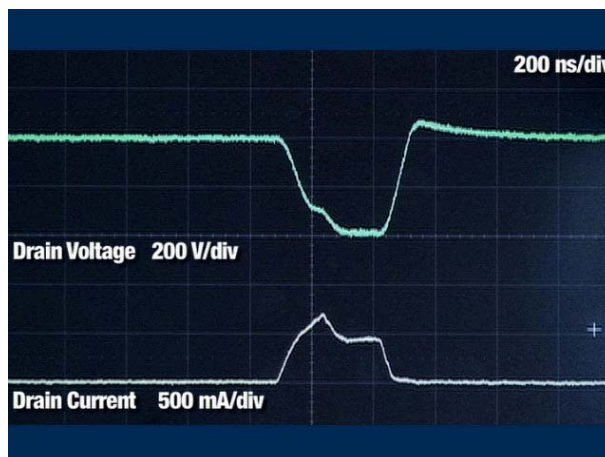
If the transformer construction and current limit programming are correct, you'll need to redesign your transformer to reduce the flux density in the core. This can be done by adding turns to your transformer, or by reducing the allowable production tolerances on primary inductance, LP. To increase the number of turns in your [PI Expert](#) design, increase the number of secondary turns, NS, and the software will also increase the number of primary turns, NP, proportionally. You may also adjust the value of KP to reduce flux density. If the primary current limit is programmable and is much higher than necessary for your power level, reducing it will also decrease flux density. In rare cases, you may need to increase your core size to reduce flux density. Adjust your design until both the Maximum Flux Density (BM) and Peak Flux Density (BP) are much lower than the limits specified by [PI Expert](#). Note that an optimized [PI Expert](#) design will always limit flux density to an acceptable level. If, while manually customizing your design, you make a change that pushes flux density too high, [PI Expert](#) will warn you of this dangerous condition.



PI Expert warnings for high flux density

Transformer saturation will also occur when the transformer core is too hot. Verify that your transformer is operating within the appropriate thermal limits when saturation is observed. If necessary, redesign your transformer to reduce core and winding losses and lower its operating temperature.

During the startup test, it is possible to capture short pulses, like the one seen here. These pulses are normal, and are caused by the lack of transformer reset at low output voltages.

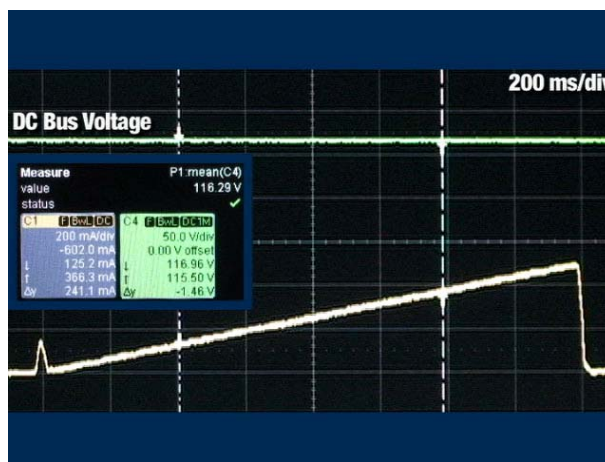


Short current pulses

Chapter 16: Transformer Primary Inductance

Now turn off the AC input and connect the high-voltage oscilloscope probe across the terminals of the input bulk capacitor. Then apply the minimum AC input to your supply and increase the output loading to full load. Configure the scope to view both the DC bus voltage, seen by the high-voltage probe connected across the bulk capacitor, and the drain switching current.

On the scope, measure the di/dt ratio of the drain current during the most linear portion of the ramp. This is typically the portion between 25 and 75 percent of the current limit. Also measure the average DC bus voltage seen during the same interval used to measure the change in current. Using these two pieces of information, you can calculate an approximate value of the primary inductance of the transformer using the basic relationship of inductors: $V = L \Delta i / \Delta t$



Measuring transformer primary inductance

When the MOSFET is turned on, the voltage seen across the transformer primary is approximately equal to the average DC bus voltage. The current through the inductor is the same as the drain current. Rearranging this equation, we calculate L as: $L = V \Delta t / \Delta i$

Compare the value you calculate with the value specified in [PI Expert](#). If it is outside of the tolerances given, then contact your transformer manufacturer to resolve this problem.

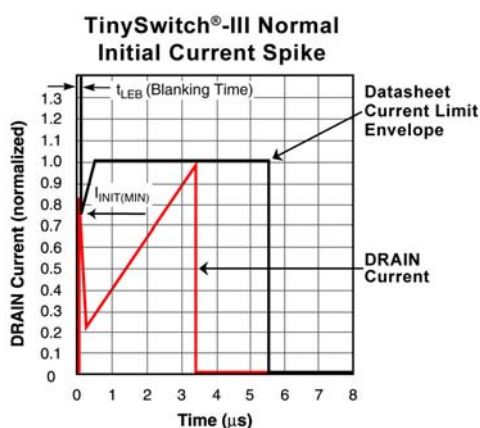
Chapter 17: Initial Current Spike

Next, check for high initial current, which occurs immediately after the MOSFET is switched on. Turn off the AC source and reconnect the high-voltage oscilloscope probe across the MOSFET to measure drain switching voltage, then apply the maximum specified AC input voltage and load your supply to full load.

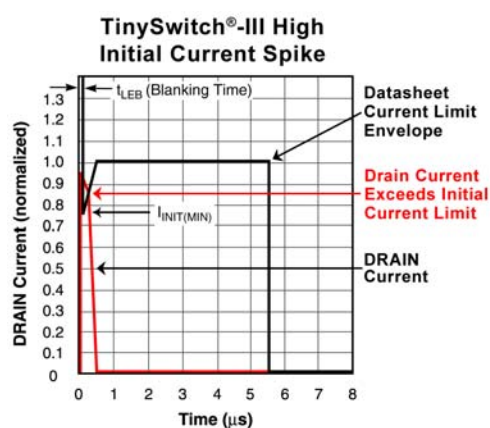
Configure your oscilloscope to view both the MOSFET voltage and current, and trigger on the rising edge of the drain voltage. Set the timebase just wide enough to monitor one complete switching cycle.

Examine the turn-on edge of the drain current waveform. You may observe a spike of current. This spike is normal in switching power supplies, and is caused by parasitic capacitances which quickly discharge through the MOSFET.

Power Integrations devices implement a leading edge blanking feature which disables the current limit sensor for a fixed period immediately following MOSFET turn on. This prevents the initial current spike from triggering the current limit and prematurely terminating the current pulse. However, if the turn-on spike is larger than normal, it can still trigger the initial current limit of the device and cause it to limit power transfer to the output.



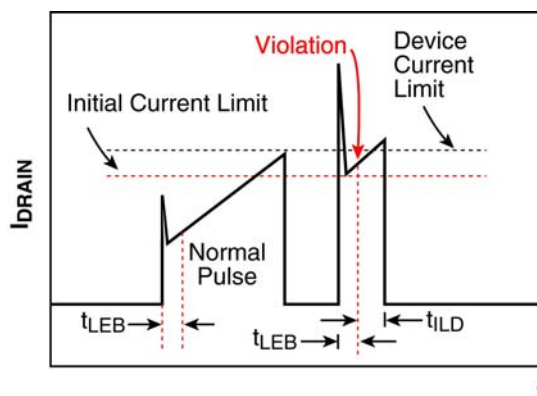
PI leading edge blanking feature



Turn-on spike causes initial current limit to be exceeded

Study the datasheet for your Power Integrations device to determine the minimum leading-edge blanking time for your design, then measure the current level you see through the MOSFET after the leading-edge blanking time. Compare this value with the initial current limit also found in the device datasheet. If the value you measure is greater than the initial current limit, then this may cause power delivery problems.

Repeat this measurement at the lowest specified input voltage. If the design operates in continuous conduction mode at low line, the initial current pedestal will add to the initial current spike.

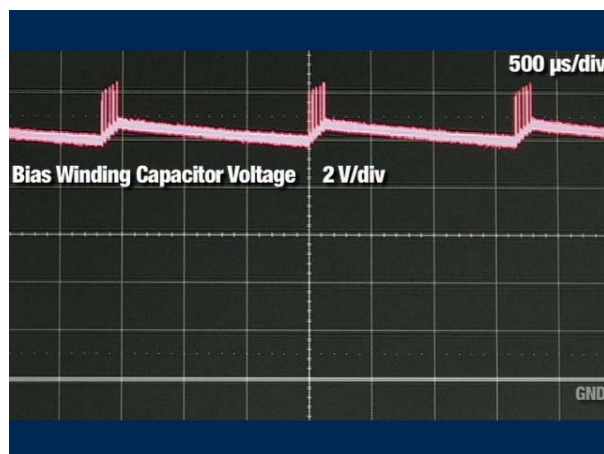


Initial current limit exceeded after leading-edge blanking

Chapter 18: Bias Winding Voltage

If your design uses a bias winding, turn off the AC input and connect an oscilloscope voltage probe, set to measure DC voltage, across the filter capacitor for the bias winding output. If necessary, solder two short leads to the back of the board as test points for this measurement. Then, apply the minimum AC input and remove all loading from the output of your supply.

On the scope, measure and record the lowest voltage you see across the bias winding capacitor over an entire cycle. If the lowest bias winding voltage you measure is less than 8 V, this can cause regulation problems in your design. To fix this, you will need to add more turns to your bias winding to increase the voltage. We suggest that you only add one turn at a time before retesting the voltage in your prototype design. Adding too many turns will increase the bias winding voltage too much, causing increased no-load dissipation in your design. It is recommended the lowest bias winding voltage at no-load be more than 8 volts, but less than approximately 9 volts. In some designs, increasing the value of the bias winding filter capacitor can provide sufficient hold-up to increase the lowest bias winding voltage above 8 volts.

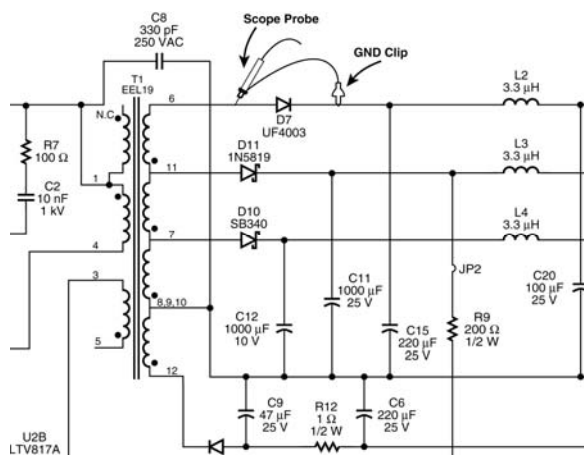


Measure lowest bias winding voltage at no-load

Chapter 19: Output Diode Peak Inverse Voltage (PIV)

Next, check the PIV across the output diode. First, turn off the AC input and disconnect all scope probes from your board, then connect a low-voltage probe across the output diode you wish to measure, connecting the ground clip to the cathode and the probe tip to the anode, as shown below. We have also inserted a current probe in series with the output diode to view diode current; however, this is not necessary for your measurement.

Apply the maximum AC input voltage and load your supply to full load. Looking at the DC voltage seen on the scope, you will notice that the voltage across the diode is close to zero while the diode is conducting and quickly reverts to a negative voltage when it is turned off. This negative voltage is the inverse voltage. Measure the highest negative voltage seen across the diode at any point and compare this value with the PIV rating of your diode. If the value you measure is equal to or greater than the diode rating, it will fail long before the expected component lifetime.



Measuring PIV across output diode

Power Integrations recommends maintaining a margin of 20% between the measured PIV and the diode rating for field reliability reasons. If your diode does not meet these requirements, replace it with one that has a larger PIV rating or, alternatively, optimize your diode snubber.

If your design has multiple outputs, repeat this test for all other output diodes in your design.

Chapter 20: Full-Load Efficiency

Next, measure and record the full-load efficiency of your power supply at both lowest and highest AC input voltage. If the full-load efficiency is less than the value predicted in [PI Expert](#) by 5% or more, you will need to address this issue.

Chapter 21: Component Temperatures

Measure the temperature of key components in your design, including diodes, electrolytic capacitors, common mode chokes, the transformer core, windings, and the Power Integrations device. These measurements should be performed while the supply is at full load and has been operating at room temperature for about 20 minutes. Take temperature measurements at both minimum and maximum AC input voltage; however, temperatures are usually highest at low line.

Extrapolating Room Temperature
Thermal Measurements

Item	85 VAC Input		
	22 °C Ambient	Adjustment (22 °C -> 50 °C)	50 °C Ambient (Approximation)
Output Cap	57	+28	85
Transformer	61	+28	79
Clamp Zener	59	+28	87
PI Device	74	+28	102
Output Diode	69	+28	97

Extrapolating room temperature thermal measurements

Increase the temperatures you recorded to approximate for the worst case by adding the difference between the measured room temperature and the maximum ambient temperature specified. Compare these estimated temperatures with the maximum operating temperatures found in the component datasheets. Be sure to factor in any derating requirements for your design when making this comparison.

Component temperatures may be derated to meet specific safety requirements or to improve the lifetime of components. For example, the allowable operating temperatures of electrolytic capacitors are a function of the expected lifetime of the component. A 105 degrees C 2,000-hour rated capacitor operated continuously at 70 degrees C will have an expected lifetime of about 20,000 hours. For your reference, a conservative list of component temperature deratings has been included here.

Component	Temp. Limit
Class B transformer	120°C
DC bulk capacitor	20°C derating
Input inductor or common mode choke	100°C
Clamp diode	115°C
Clamp Zener	115°C
PI device	110°C
Output diodes	115°C
Output capacitors	20°C derating
Bridge rectifier	115°C
Inrush limiter (thermistor)	150°C
MOV (metal oxide varistor)	40°C

Conservative temperature limits at highest ambient

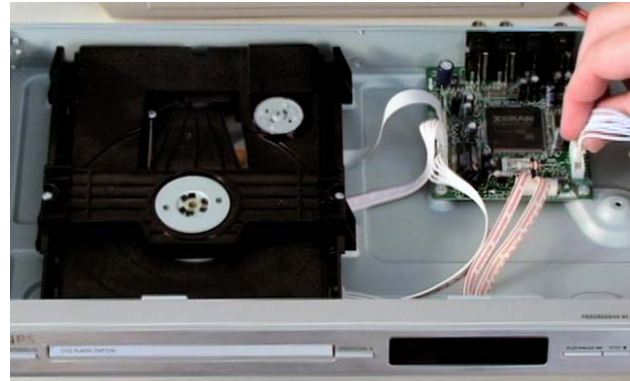
If you see discoloration of a component or the PCB, or if a component is visibly smoking, then turn off the AC input immediately and address this problem.

Chapter 22: Output Voltage Ripple

Now, measure the output voltage ripple and confirm that it is within the limits specified for your design. If it is not, or if you see significant oscillation on the output, then see the [PI University](#) troubleshooting curriculum to address this problem.

Chapter 23: Startup with Final Load

Finally, turn off the AC input, remove the electronic loads from the power supply output, and connect your actual load. Connect a multimeter across the output of the power supply to monitor output voltage. Set the AC source to the maximum AC voltage for your design and snap it on. Verify that the power supply is able to start up and reach regulation while powering the actual load.



Operation with the actual load

Repeat this test again with the AC voltage set to the minimum limit. If your power supply cannot start up when the actual load is attached, you will need to see the [PI University](#) troubleshooting course, [Fixing a Flyback Supply Where the Output Fails to Reach Regulation](#), to debug this issue.

Chapter 24: Powering the Final Load

If your load has different operational modes, be sure to cycle through all of them and ensure that the power supply never enters auto-restart. If it does, your actual load is drawing more power than your supply is designed to deliver. You will need to carefully characterize your load and redesign your power supply.

For More Information

If you have any questions or comments about the information presented in this course, please email PIUniversity@powerint.com.