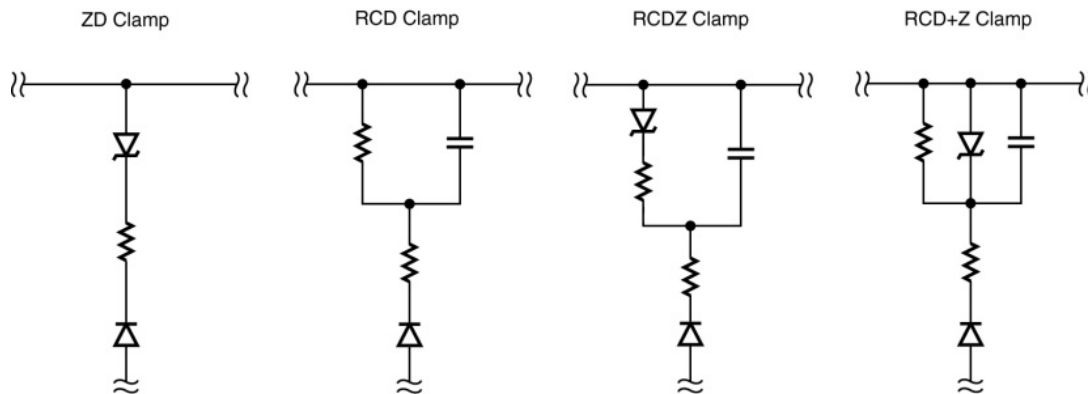


### Introduction

This document provides a step-by-step procedure for sizing components in each of the four major clamp type circuits for a flyback power supply designed using *PI Expert*<sup>(R)</sup>. Any assumptions made or approximations used have been noted, where appropriate. Note that a clamp design created by *PI Expert* may be slightly more conservative than one generated by the algorithm provided here. After an initial design of your clamp circuit, you should construct a prototype and verify its performance in your supply. If the results are significantly different than expected, reiterate the design.



The Four Clamp Types

### Sizing an RCD Clamp

1. Measure the primary leakage inductance of your transformer,  $L_L$
2. Check the switching frequency of your design used in *PI Expert*,  $f_s$
3. Determine the correct primary current,  $I_p$ , as follows:  
(Note: All values found in *PI Expert*)
  - a. If your design uses power limit programming,  $I_p = I_{LIMITEXT}$
  - b. If your design uses external current limit programming,  $I_p = I_{LIMITEXT}$
  - c. For all other designs,  $I_p = I_{LIMITMAX}$

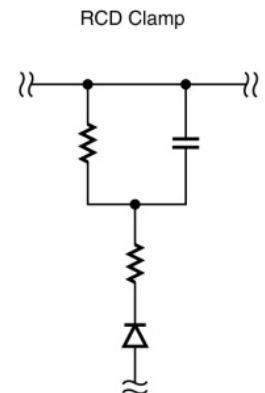
4. Determine the total voltage allowed across the primary MOSFET and calculate  $V_{maxclamp}$  as:

$$V_{MOSFETmax} = (V_{AC_{HighLine}} * \sqrt{2}) + V_{maxclamp}$$

(Note: It is recommended that at least a 50 V margin be maintained below  $BVDSS$  for a MOSFET, with an additional 30 to 50 V margin to account for transient voltages. For universal input designs, it is recommended that  $V_{maxclamp} < 200$  V.  $V_{maxclamp}$  should never be less than approximately  $1.5 * VOR$ .)

5. Determine the voltage ripple across the clamp circuit,  $V_{delta}$   
(Note: Typical value of 10% of  $V_{maxclamp}$  recommended.)
6. Calculate the minimum voltage across the clamp circuit as:

$$V_{minclamp} = V_{maxclamp} - V_{delta}$$



7. Calculate the average voltage across the clamp circuit,  $V_{clamp}$  as:

$$V_{clamp} = V_{maxclamp} - \frac{V_{delta}}{2}$$

8. Calculate energy stored in leakage reactance as:

$$E_{LL} = \frac{1}{2} * L_L * I_P^2$$

(Note: Not all leakage reactance energy is transferred to the clamp. As a result, the true energy dissipated by the clamp should be calculated using the above equation and substituting the peak primary current,  $I_P$ , with the current that only flows in the clamp:  $I_C$ . Because  $I_C$  is difficult to calculate or measure, we will adjust  $E_{LL}$  by a known scale factor to estimate the energy dissipated in the clamp:  $E_{clamp}$ .)

9. Estimate energy dissipated in the clamp,  $E_{clamp}$ , as:

$$1.5 W \leq P_{out} \leq 50 W \quad E_{clamp} = 0.8 * E_{LL}$$

$$50 W < P_{out} \leq 90 W \quad E_{clamp} = E_{LL}$$

$$90 W < P_{out} \quad E_{clamp} = E_{LL} * \left( \frac{V_{clamp}}{V_{clamp} - V_{OR}} \right)$$

(Note: Clamp circuits are not typically required in power supplies with a continuous output power < 1.5 W.)

10. Calculate the clamp resistor value as:

$$R_{clamp} = \frac{V_{clamp}^2}{E_{clamp} * f_s}$$

(Note: The  $R_{clamp}$  value calculated here is a first approximation. After the power supply has been built, measure the average voltage  $V_{clamp}$  and compare it with the value used here. If the measured value is lower than expected, increase the value of  $R_{clamp}$  until the measured value matches these calculations. If the measured value is higher than expected, decrease the value of  $R_{clamp}$ .)

11. The clamp resistor power rating should be more than:

$$\frac{V_{clamp}^2}{R_{clamp}}$$

12. Calculate the clamp capacitor value as:

$$C_{clamp} = \frac{E_{clamp}}{\frac{1}{2} * [V_{maxclamp}^2 - V_{minclamp}^2]}$$

13. The clamp capacitor voltage rating should be more than:  $1.5 * V_{maxclamp}$

14. A fast or ultra-fast recovery diode should be used as the blocking diode in a clamp circuit.

(Note: Under some circumstances, the use of a standard recovery diode may provide some improvement in efficiency and EMI. The standard recovery diode used for such a purpose **must** have a specified reverse recovery time listed. Careful attention should be paid to the reverse recovery current in this diode to ensure it is below acceptable limits. The approval of a standard recovery diode based design is not recommended without thorough evaluation.)

15. The PIV of the blocking diode should be more than:  $1.5 * V_{maxclamp}$

16. The forward peak repetitive current rating of the blocking diode should be more than:  $I_P$

If this parameter is not listed in the datasheet, the average forward current rating should be more than:  $0.5 * I_P$

(Note: The average forward current rating of the diode may be specified lower, and is primarily constrained by thermal performance. The temperature of the blocking diode should be measured during steady-state operation at lowest input voltage to determine if the rating is appropriate. Heatsinking, component orientation, and final product enclosure all affect the operating temperature of the diode.)

17. Size the damping resistor (if used) as:

$$\frac{20}{0.8 \cdot I_p} \Omega \leq R_{damp} \leq 100 \Omega$$

(Note: For systems with a maximum continuous output power of 20 W or more,  $R_{damp}$  should only be used if absolutely necessary and should be restricted to a very small value:  $1 \Omega \leq R_{damp} \leq 4.7 \Omega$ .)

18. The damping resistor power rating should be more than:

$$I_p^2 * R_{damp}$$

### Sizing a ZD Clamp

1. Measure the primary leakage inductance of your transformer,  $L_L$
2. Check the switching frequency of your design used in [PI Expert](#),  $f_s$
3. Determine the correct primary current,  $I_p$ , as follows:

(Note: all values found in [PI Expert](#))

- a. If your design uses power limit programming,  $I_p = I_{LIMITEXT}$
- b. If your design uses external current limit programming,  $I_p = I_{LIMITEXT}$
- c. For all other designs,  $I_p = I_{LIMITMAX}$

4. Determine the total voltage allowed across the primary MOSFET and calculate  $V_{maxclamp}$  as:

$$V_{maxclamp} \text{ as: } V_{MOSFETmax} = (V_{AC_{HighLine}} * \sqrt{2}) + V_{maxclamp}$$

(Note: It is recommended that at least a 50 V margin be maintained below BVDSS for a MOSFET, with an additional 30 to 50 V margin to account for transient voltages. For universal input designs, it is recommended that  $V_{maxclamp} < 200$  V.  $V_{maxclamp}$  should never be less than approximately  $1.5 * V_{OR}$ .)

5. Calculate energy stored in leakage reactance as:

$$E_{LL} = \frac{1}{2} * L_L * I_p^2$$

(Note: Not all leakage reactance energy is transferred to the clamp. As a result, the true energy dissipated by the clamp should be calculated using the above equation and substituting the peak primary current,  $I_p$ , with the current that only flows in the clamp:  $I_C$ . Because  $I_C$  is difficult to calculate or measure, we will adjust  $E_{LL}$  by a known scale factor to estimate the energy dissipated in the clamp:  $E_{clamp}$ .)

6. Estimate energy dissipated in the clamp,  $E_{clamp}$ , as:

$$1.5 W \leq P_{out} \leq 50 W \quad E_{clamp} = 0.8 * E_{LL}$$

$$50 W < P_{out} \leq 90 W \quad E_{clamp} = E_{LL}$$

$$90 W < P_{out} \quad E_{clamp} = E_{LL} * \left( \frac{V_{clamp}}{V_{clamp} - V_{OR}} \right)$$

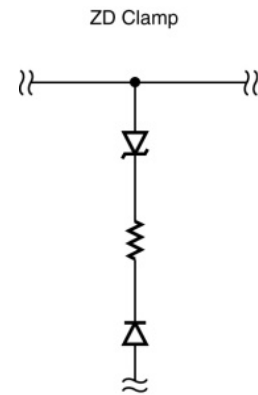
(Note: Clamp circuits are not typically required in power supplies with a continuous output power  $< 1.5$  W.)

7. The TVS breakdown voltage is specified as:  $V_{maxclamp}$

(Note: Round up, when necessary. A TVS must be used because a Zener diode cannot withstand the instantaneous peak power dissipated in the device.)

8. The TVS power rating should be at least  $1.5 * E_{clamp} * f_s$

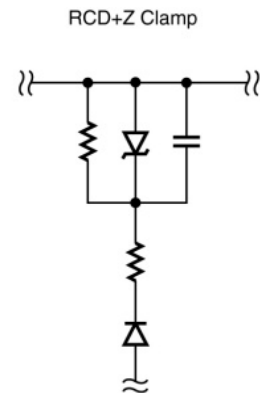
(Note: Use multiple TVS components in parallel to achieve power derating, if necessary. Verify that the TVS power rating is correct by measuring its temperature while the supply is running at full load and lowest input voltage. The body of a TVS should never exceed  $70^\circ\text{C}$  when operated at a  $25^\circ\text{C}$  ambient temperature. If your TVS is hotter than this, use a component rated for higher power or use multiple TVS components in parallel.)



9. A fast or ultra-fast recovery diode should be used as the blocking diode in a clamp circuit.  
(Note: Under some circumstances, the use of a standard recovery diode may provide some improvement in efficiency and EMI. The standard recovery diode used for such a purpose **must** have a specified reverse recovery time listed. Careful attention should be paid to the reverse recovery current in this diode to ensure it is below acceptable limits. The approval of a standard recovery diode based design is not recommended without thorough evaluation.)
10. The PIV of the blocking diode should be more than:  $1.5 * V_{maxclamp}$
11. The forward peak repetitive current rating of the blocking diode should be more than:  $I_p$   
If this parameter is not listed in the datasheet, the average forward current rating should be more than:  $0.5 * I_p$   
(Note: The average forward current rating of the diode may be specified lower, and is primarily constrained by thermal performance. The temperature of the blocking diode should be measured during steady-state operation at lowest input voltage to determine if the rating is appropriate. Heatsinking, component orientation, and final product enclosure all affect the operating temperate of the diode.)
12. Size the damping resistor (if used) as:  
$$\frac{20}{0.8 * I_p} \Omega \leq R_{damp} \leq 100 \Omega$$
  
(Note: For systems with a maximum continuous output power of 20 W or more,  $R_{damp}$  should only be used if absolutely necessary and should be restricted to a very small value:  $1 \Omega \leq R_{damp} \leq 4.7 \Omega$ .)
13. The damping resistor power rating should be more than:  
 $I_p^2 * R_{damp}$

### Sizing an RCD+Z Clamp

1. Measure the primary leakage inductance of your transformer,  $L_L$
2. Check the switching frequency of your design used in [PI Expert](#),  $f_s$
3. Check the peak primary current predicted by [PI Expert](#),  $I_p$
4. Determine the total voltage allowed across the primary MOSFET and calculate  $V_{maxclamp}$  as:  
$$V_{MOSFETmax} = (VAC_{HighLine} * \sqrt{2}) + V_{maxclamp}$$
  
(Note: It is recommended that at least a 50 V margin be maintained below BVDS for a MOSFET, with an additional 30 to 50 V margin to account for transient voltages. For universal input designs, it is recommended that  $V_{maxclamp} < 200$  V.  $V_{maxclamp}$  should never be less than approximately  $1.5 * V_{OR}$ .)
5. Determine the voltage ripple across the clamp circuit,  $V_{delta}$   
(Note: typical value of 10% of  $V_{maxclamp}$  recommended)
6. Calculate the minimum voltage across the clamp circuit as:  
$$V_{minclamp} = V_{maxclamp} - V_{delta}$$
7. Calculate the average voltage across the clamp circuit,  $V_{clamp}$  as:  
$$V_{clamp} = V_{maxclamp} - \frac{V_{delta}}{2}$$
8. Calculate energy stored in leakage reactance as:  
$$E_{LL} = \frac{1}{2} * L_L * I_p^2$$
  
(Note: Not all leakage reactance energy is transferred to the clamp. As a result, the true energy dissipated by the clamp should be calculated using the above equation and substituting the peak primary current,  $I_p$ , with the current that only flows in the clamp:  $I_C$ . Because  $I_C$  is difficult to calculate or measure, we will adjust  $E_{LL}$  by a known scale factor to estimate the energy dissipated in the clamp:  $E_{clamp}$ .)



9. Estimate energy dissipated in the clamp,  $E_{clamp}$ , as:

$$1.5 W \leq P_{out} \leq 50 W \quad E_{clamp} = 0.8 * E_{LL}$$

$$50 W < P_{out} \leq 90 W \quad E_{clamp} = E_{LL}$$

$$90 W < P_{out} \quad E_{clamp} = E_{LL} * \left( \frac{V_{clamp}}{V_{clamp} - V_{OR}} \right)$$

(Note: Clamp circuits are not typically required in power supplies with a continuous output power < 1.5 W.)

10. Calculate the clamp resistor value as:

$$R_{clamp} = \frac{V_{clamp}^2}{E_{clamp} * f_s}$$

(Note: The  $R_{clamp}$  value calculated here is a first approximation. After the power supply has been built, measure the average voltage  $V_{clamp}$  and compare it with the value used here. If the value you measure is lower than expected, increase the value of  $R_{clamp}$  until the measured value matches these calculations. If the measured value is higher than expected, decrease the value of  $R_{clamp}$ .)

11. The clamp resistor power rating should be more than:

$$\frac{V_{clamp}^2}{R_{clamp}}$$

12. Calculate the clamp capacitor value as:

$$C_{clamp} = \frac{E_{clamp}}{\frac{1}{2} * [V_{maxclamp}^2 - V_{minclamp}^2]}$$

13. The clamp capacitor voltage rating should be more than:  $1.5 * V_{maxclamp}$

14. Specify the TVS breakdown voltage as approximately:  $V_Z = V_{maxclamp} + 20 V$

(Note: A TVS must be used because a Zener diode cannot withstand the instantaneous peak power seen across the device at turn on.)

15. The TVS power rating should be sized to handle the difference in energy stored during normal operation and overload:

$$P_{TVS} > \frac{1}{2} * L_L * [I_{LIMITMAX}^2 - I_P^2] * f_s$$

(Note: All current limit values found in [PI Expert](#).)

16. A fast or ultra-fast recovery diode should be used as the blocking diode in a clamp circuit.

(Note: Under some circumstances, the use of a standard recovery diode may provide some improvement in efficiency and EMI. The standard recovery diode used for such a purpose **must** have a specified reverse recovery time listed. Careful attention should be paid to the reverse recovery current in this diode to ensure it is below acceptable limits. The approval of a standard recovery diode based design is not recommended without thorough evaluation.)

17. The PIV of the blocking diode should be more than:  $1.5 * V_{maxclamp}$

18. The forward peak repetitive current rating of the blocking diode should be more than:  $I_P$

If this parameter is not listed in the datasheet, the average forward current rating should be more than:  $0.5 * I_P$

(Note: The average forward current rating of the diode may be specified lower, and is primarily constrained by thermal performance. The temperature of the blocking diode should be measured during steady-state operation at lowest input voltage to determine if the rating is appropriate. Heatsinking, component orientation, and final product enclosure all affect the operating temperature of the diode.)

19. Size the damping resistor (if used) as:

$$\frac{20}{0.8 * I_P} \Omega \leq R_{damp} \leq 100 \Omega$$

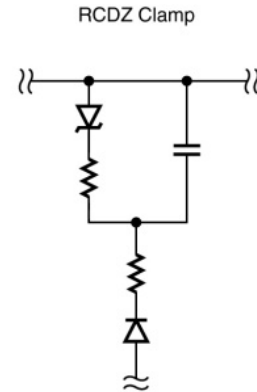
(Note: For systems with a maximum continuous output power for 20 W or more,  $R_{damp}$  should only be used if absolutely necessary and should be restricted to a very small value:  $1 \Omega \leq R_{damp} \leq 4.7 \Omega$ .)

20. The damping resistor power rating should be more than:

$$I_p^2 * R_{damp}$$

### Sizing an RCDZ Clamp

1. Measure the primary leakage inductance of your transformer,  $L_L$
2. Check the switching frequency of your design used in [PI Expert](#),  $f_s$
3. Determine the correct primary current,  $I_p$ , as follows:  
(Note: All values found in [PI Expert](#).)
  - a. If your design uses power limit programming,  $I_p = I_{LIMITTEXT}$
  - b. If your design uses external current limit programming,  $I_p = I_{LIMITTEXT}$
  - c. For all other designs,  $I_p = I_{LIMITMAX}$



4. Determine the total voltage allowed across the primary MOSFET and calculate  $V_{maxclamp}$  as:

$$V_{MOSFETmax} = (VAC_{HighLine} * \sqrt{2}) + V_{maxclamp}$$

(Note: It is recommended that at least a 50 V margin be maintained below BVDS for a MOSFET, with an additional 30 to 50 V margin to account for transient voltages. For universal input designs, it is recommended that  $V_{maxclamp} < 200$  V.  $V_{maxclamp}$  should never be less than approximately  $1.5 * VOR$ .)

5. Determine the voltage ripple across the clamp circuit,  $V_{delta}$   
(Note: Typical value of 10% of  $V_{maxclamp}$  recommended.)

6. Calculate the minimum voltage across the clamp circuit as:

$$V_{minclamp} = V_{maxclamp} - V_{delta}$$

7. Calculate the average voltage across the clamp circuit,  $V_{clamp}$  as:

$$V_{clamp} = V_{maxclamp} - \frac{V_{delta}}{2}$$

8. Calculate energy stored in leakage reactance as:

$$E_{LL} = \frac{1}{2} * L_L * I_p^2$$

(Note: Not all leakage reactance energy is transferred to the clamp. As a result, the true energy dissipated by the clamp should be calculated using the above equation and substituting the peak primary current,  $I_p$ , with the current that only flows in the clamp:  $I_C$ . Because  $I_C$  is difficult to calculate or measure, we will adjust  $E_{LL}$  by a known scale factor to estimate the energy dissipated in the clamp:  $E_{clamp}$ .)

9. Estimate energy dissipated in the clamp,  $E_{clamp}$ , as:

$$1.5 W \leq P_{out} \leq 50 W \quad E_{clamp} = 0.8 * E_{LL}$$

$$50 W < P_{out} \leq 90 W \quad E_{clamp} = E_{LL}$$

$$90 W < P_{out} \quad E_{clamp} = E_{LL} * \left( \frac{V_{clamp}}{V_{clamp} - VOR} \right)$$

(Note: Clamp circuits are not typically required in power supplies with a continuous output power  $< 1.5$  W.)

10. The Zener breakdown voltage is specified as:  $V_Z \geq VOR$

(Note: Round up, when necessary.  $V_Z$  should never be specified as less than  $VOR$ .)

11. Calculate the clamp resistor value as:

$$R_{clamp} = \frac{(V_{clamp} - V_Z)^2}{E_{clamp} * f_s}$$

12. Calculate the power rating of the clamp resistor as:

$$1.5 * \frac{[V_{clamp} - V_z]^2}{R_{clamp}}$$

(Note: The  $R_{clamp}$  value calculated here is a first approximation. After the power supply has been built, measure the average voltage  $V_{clamp}$  and compare it with the value used here. If the value you measure is lower than expected, increase the value of  $R_{clamp}$  until the measured value matches these calculations. If the measured value is higher than expected, decrease the value of  $R_{clamp}$ .)

13. The Zener power rating should be specified as more than:

$$1.5 * V_z * \left[ \frac{E_{clamp} * f_s}{V_{clamp}} \right]$$

(Note: Use multiple Zeners in parallel to achieve power derating, if necessary. If the power rating is too large for a Zener diode, a TVS may be used instead. Verify that the Zener power rating is correct by measuring its temperature while the supply is running at full load and lowest input voltage. The body of a Zener should never exceed 70°C when operated at a 25°C ambient temperature.)

14. Calculate the clamp capacitor value as:

$$C_{clamp} = \frac{E_{clamp}}{\frac{1}{2} * [V_{maxclamp}^2 - V_{minclamp}^2]}$$

15. The clamp capacitor voltage rating should be more than:  $1.5 * V_{maxclamp}$

16. A fast or ultra-fast recovery diode should be used as the blocking diode in a clamp circuit.

(Note: Under some circumstances, the use of a standard recovery diode may provide some improvement in efficiency and EMI. The standard recovery diode used for such a purpose **must** have a specified reverse recovery time listed. Careful attention should be paid to the reverse recovery current in this diode to ensure it is below acceptable limits. The approval of a standard recovery diode based design is not recommended without thorough evaluation.)

17. The PIV of the blocking diode should be more than:  $1.5 * V_{maxclamp}$

18. The forward peak repetitive current rating of the blocking diode should be more than:  $I_p$

If this parameter is not listed in the datasheet, the average forward current rating should be more than:  $0.5 * I_p$

(Note: The average forward current rating of the diode may be specified lower, and is primarily constrained by thermal performance. The temperature of the blocking diode should be measured during steady-state operation at lowest input voltage to determine if the rating is appropriate. Heatsinking, component orientation, and final product enclosure all affect the operating temperature of the diode.)

19. Size the damping resistor (if used) as:

$$\frac{20}{0.8 * I_p} \Omega \leq R_{damp} \leq 100 \Omega$$

(Note: For systems with a maximum continuous output power for 20 W or more,  $R_{damp}$  should only be used if absolutely necessary and should be restricted to a very small value:  $1 \Omega \leq R_{damp} \leq 4.7 \Omega$ .)

20. The damping resistor power rating should be more than:

$$I_p^2 * R_{damp}$$

### For More Information

If you have any questions about the information presented in this document, please post your inquiry on the [PI Power Supply Design Forum](#).