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APPLICATION NOTE

NEW ULTRAFAST RECOVERY DIODE TECHNOLOGY IMPROVES PERFORMANCE OF HIGH FREQUENCY POWER CIRCUITS

Presented at HFPC '93 USA

Presents a comparison between APT's new FRED and two competitor's devices

NEW ULTRAFAST RECOVERY DIODE TECHNOLOGY IMPROVES PERFORMANCE OF HIGH FREQUENCY POWER CIRCUITS

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ABSTRACT

The paper defines the different types of power losses in the active component of a Power Factor Correction (PFC) circuit. It covers how the boost diode reverse recovery characteristics relate to the power switch turn-on switching loss. It covers why reverse recovery softness is possibly the most important characteristic. The performance of an APT Fast Recovery Epitaxial Diode (FRED) and a similarly rated FRED from another manufacturer are evaluated in a simulated PFC circuit operating at 100 KHz. The increase in switching losses, as a result of different snappiness, is compared between the APT FRED and the competitor's FRED. The APT FRED was shown to greatly reduce the switching losses attributed to diode commutation. The APT FRED is constructed using an optimum diffusion profile, with high voltage epitaxial silicon and Platinum heavy metal minority carrier lifetime control.

Introduction

Minimizing switching losses is essential in high frequency power conversion circuits. Switching losses are minimized by reducing the transition time between the on-off or off-on states of the power switch. When the commutation of a diode is involved in the turn-on of the power device, the losses due to reverse recovery characteristics of a standard diode become excessive. A FRED is used to minimize these losses. However, FREDs have brought with them a new set of problems due to snappy recovery. A new FRED has been developed by APT which has improved snappiness and offers exceptional reverse recovery characteristics.

Advanced Power Technology FRED Process

The APT FRED technology uses special high voltage epitaxial silicon combined with an optimized "P" diffusion for low forward voltage drop. A state-of-the-art guard ring termination is employed to minimize leakage current, guarantee stable breakdown voltage and improve reliability of the diode. This is all combined with a proprietary Platinum heavy metal minority carrier lifetime control process to produce a FRED with superior characteristics when compared to other FREDs on the market.

The APT Platinum process has overcome the shortcomings of other heavy metal lifetime control processes. APT has found a way to limit the amount of Platinum diffused into the silicon and get it where it will do the most good. The benefits are faster recovery time, lower peak recovery current and softer recovery (Figure 1). Platinum compared to Gold provides lower leakage current at high temperature and faster recovery times at high forward current[1].

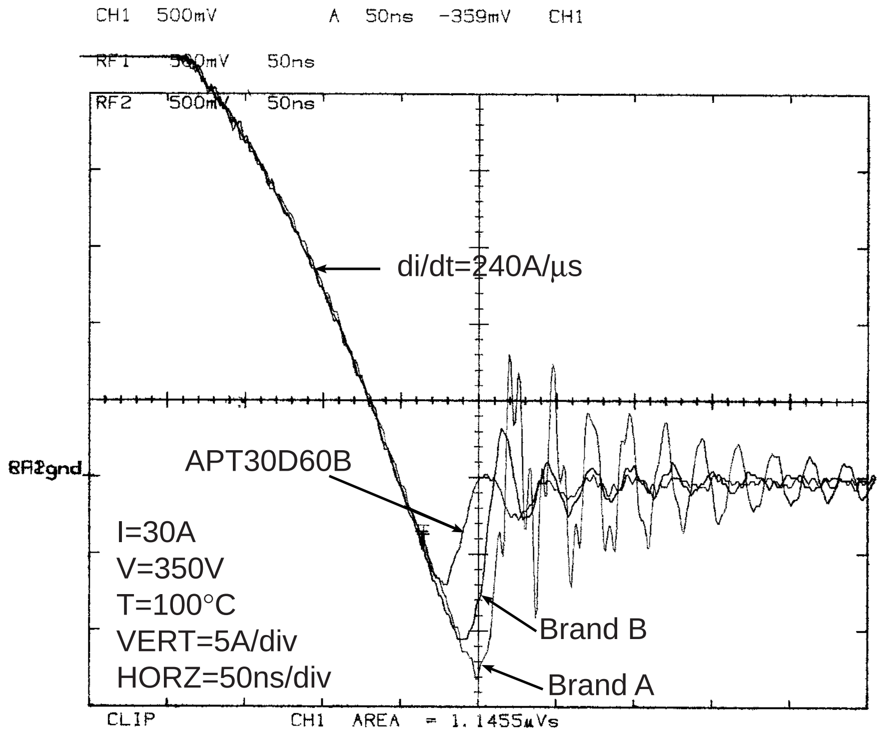


Figure 1

Power Factor Correction Circuit Losses

Understanding the losses in the active components of a boost type Power Factor Correction (PFC) circuit (Figure 2), best illustrates the benefits of using a boost diode with very soft recovery. The discussion will concentrate on the losses influenced most by the boost diode recovery characteristics.

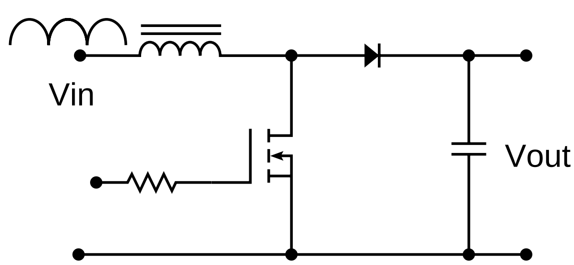


Figure 2

Conduction losses occur when the active components are conducting forward current. The boost diode conduction loss is the product of inductor current multiplied by the forward voltage drop. The MOSFET conduction loss is the product of inductor current squared multiplied by the $R_{DS(ON)}$. Conduction losses typically account for 55% of the total power losses of the PFC circuit. Conduction losses are not influenced by the reverse recovery characteristics of the boost diode.

Switching energy losses occur when the inductor current is commutated between the MOSFET and the boost diode. The switching energy losses are a function of the instantaneous power generated by the device and the time required to complete the commutation. The switching energy losses during the commutation of current from the boost diode to the MOSFET are influenced the most by the diode reverse recovery characteristics.

The boost diode turn-off switching energy loss is illustrated in Figure 3. The period to the start of the turn-off, through t_1, the peak reverse current, has very little energy loss as the diode forward voltage remains very low during this period, keeping the instantaneous power low. The period t_1 through t_2, where the reverse recovery current drops from it's peak back to zero, has some energy loss as the diode begins to block voltage during this period resulting in an increase in instantaneous power. Diode turn-off switching losses typically account for 5% of the total power losses of the PFC circuit.

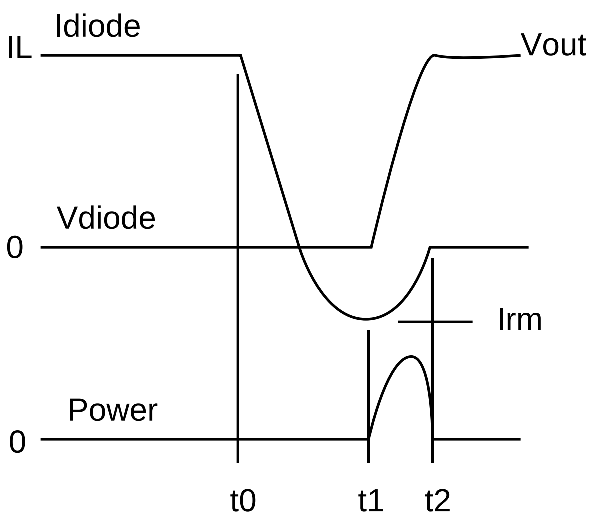


Figure 3

The boost diode turn-on switching energy loss is illustrated in Figure 4. The turn-on switching energy loss is defined as the result of the high forward voltage observed during the turn-on period of the diode. Diode forward recovery time is defined as the time it takes the junction to become fully conductive. Actually, diode forward recovery time measurements are dominated by package inductance. The energy stored in the inductance will be delivered to the load during diode turn-off and not dissipated at all. Therefore, the diode turn-off loss can be ignored.

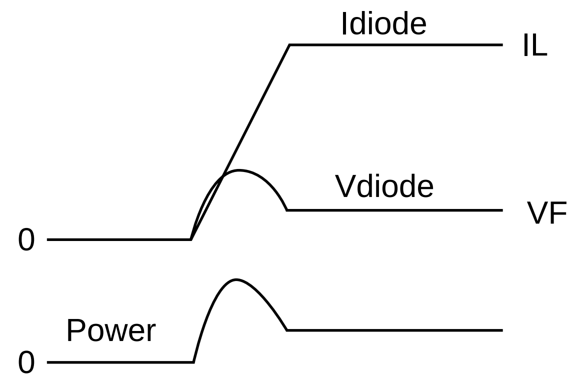


Figure 4

The MOSFET turn-on switching loss is illustrated in Figure 5. MOSFET turn-on switching losses begin at t_0, the start of Drain current flow, and continue through t_4, where the Drain voltage reaches the on voltage and conduction loss begins. MOSFET turn-on switching losses typically account for 30% of the total power losses of the PFC circuit.

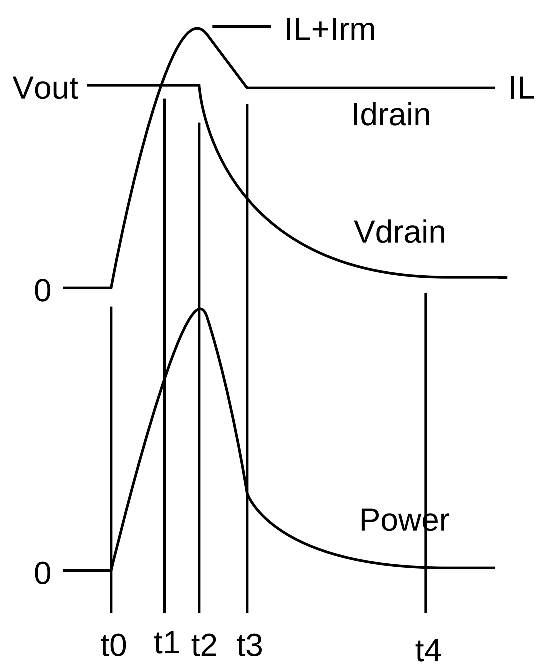


Figure 5

The period t_0 through t_1 is the time required for the inductor current to be commutated from the boost diode to the MOSFET. The amount of energy loss during this period is considerable because the drain voltage remains high as the drain current is increasing, resulting in high instantaneous power. The time required to make this transition is controlled by the MOSFET and drive circuit characteristics.

The period t_1 through t_2 is the time required for the diode reverse recovery current to reach its peak value. The amount of energy loss during this period is considerable because the current continues to increase as the drain voltage remains high, resulting in even higher instantaneous power. The time required to make this transition and the peak current reached is controlled by the boost diode recovery characteristics.

The period t_2 through t_3 is the time required for the diode reverse recovery current to decrease from its peak value to the inductor current value. The amount of energy loss during this period is considerable because the current remains high while the drain voltage falls towards the on voltage of the MOSFET. A portion of this loss is the result of the boost diode recovery characteristics.

The period t_3 through t_4 is the time required for the Drain voltage to complete the transition to the on voltage. Energy may or may not be lost during this period because the Drain current remains at the inductor current but the drain voltage may or may not have completed the transition to the on voltage of the MOSFET. This period is not required with a non snappy boost diode. The relationship will be explored in the next section.

The MOSFET turn-off switching loss is illustrated in Figure 6. MOSFET turn-off switching losses begin at t_0, the point where the Drain begins to increase, and continue through t_2, where the Drain current reaches zero. MOSFET turn-off switching losses are not influenced by the boost diode characteristics except that the turn-off switching time may be longer than necessary due to the gate drive requirements to accommodate the reverse recovery characteristics of the boost diode. This can be mitigated by proper gate drive design. MOSFET turn-off switching losses typically account for 13% of the total power losses of the PFC circuit.

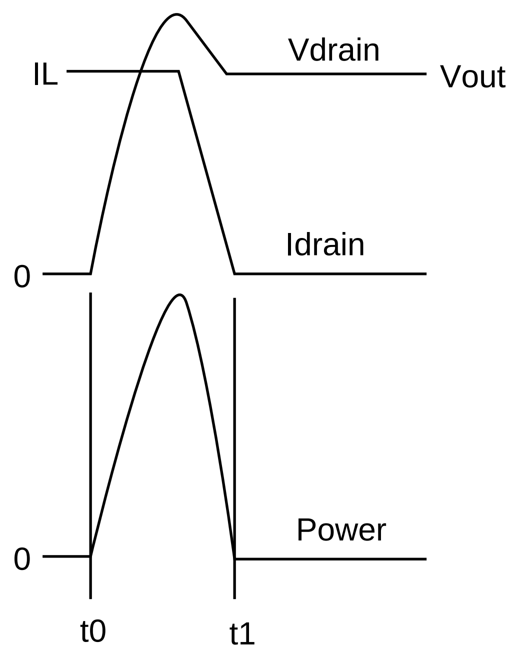


Figure 6

<u>Diode Comparison</u>

From the preceding discussion, it seems the simplest way to reduce the MOSFET turn-off switching energy losses would be to switch at the fastest speed possible. This of course is true only to a point. The faster the boost diode is forced to recover, the higher the peak recovery current becomes, negating some of the switching loss savings. The optimum commutation point was found to be between 300 to 400 Amps/µsec[2].

Another consideration is the faster the boost diode is forced to recover, the snappier the recovery characteristic becomes. A point is reached where the snappiness causes excessive ringing and will increase the EMI generated. This may cause problems in the control circuitry or will result in

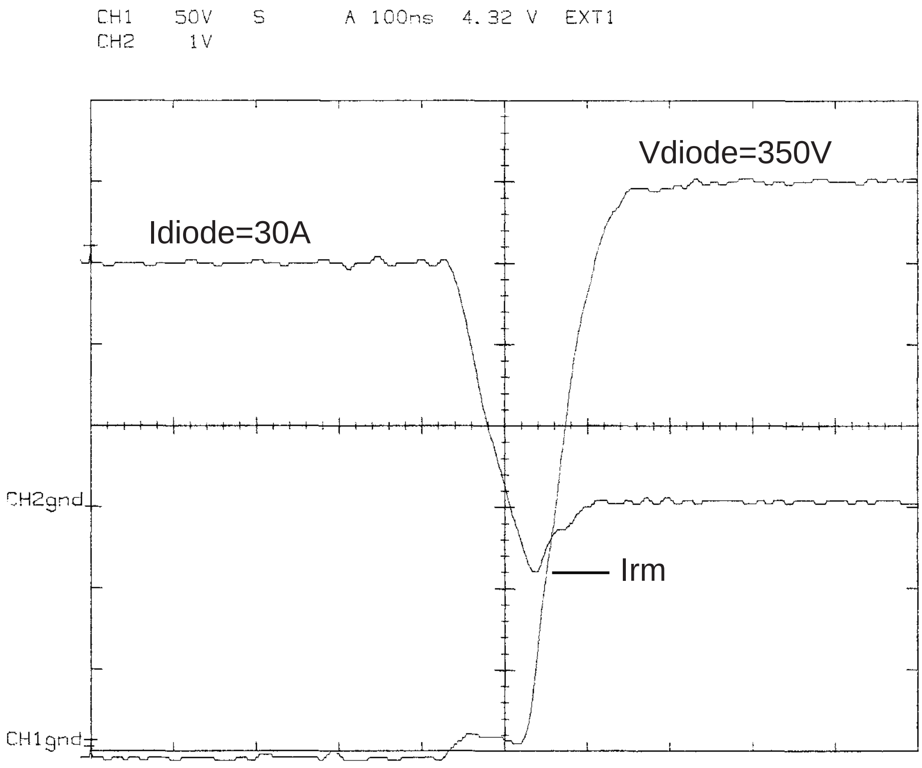


Figure 7. APT30D60B

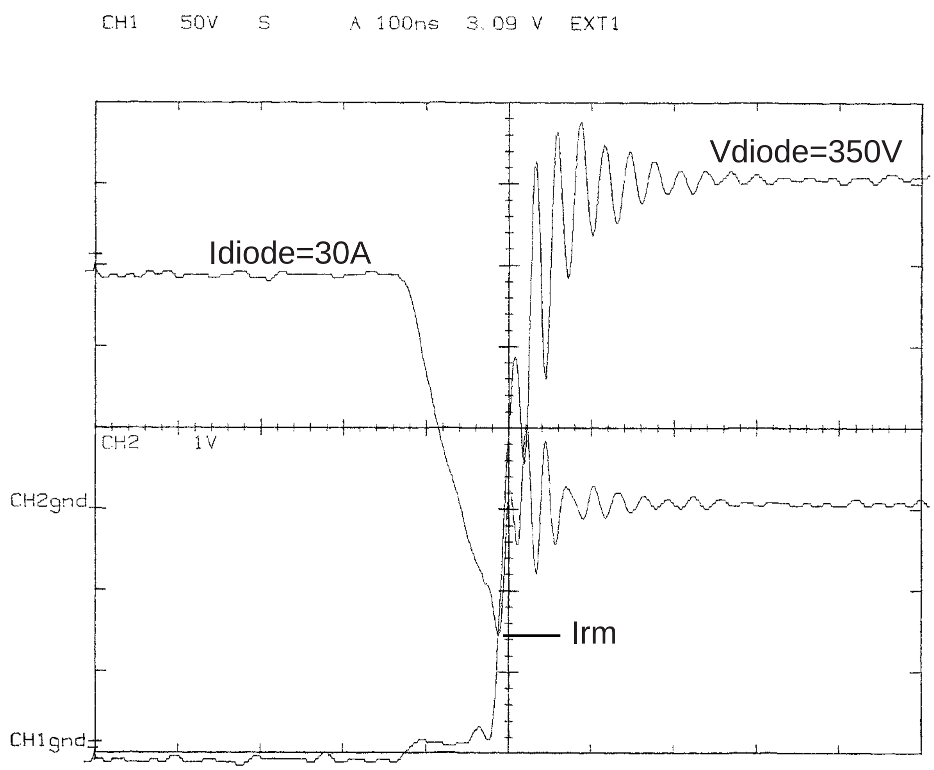


Figure 8. Brand A

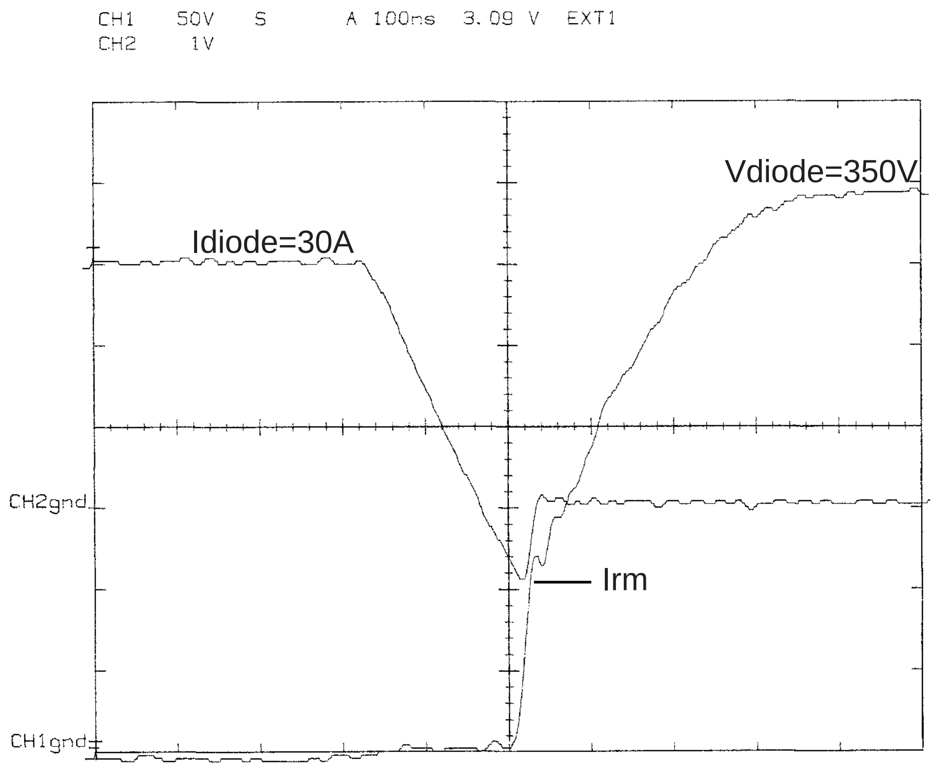


Figure 9. Brand A

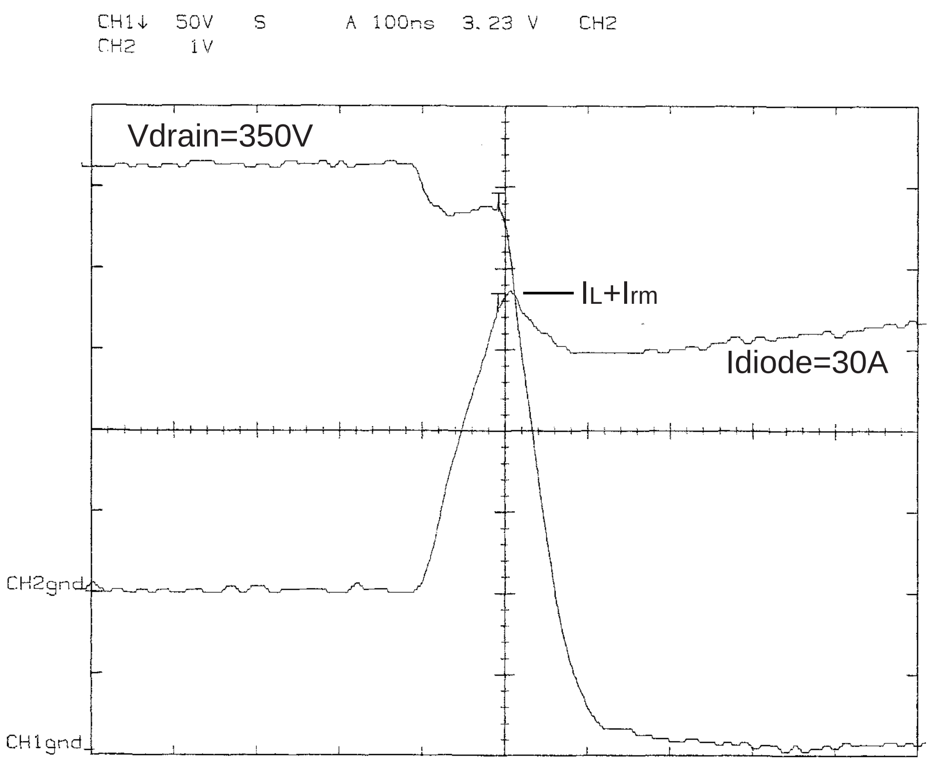


Figure 10. APT30D60B

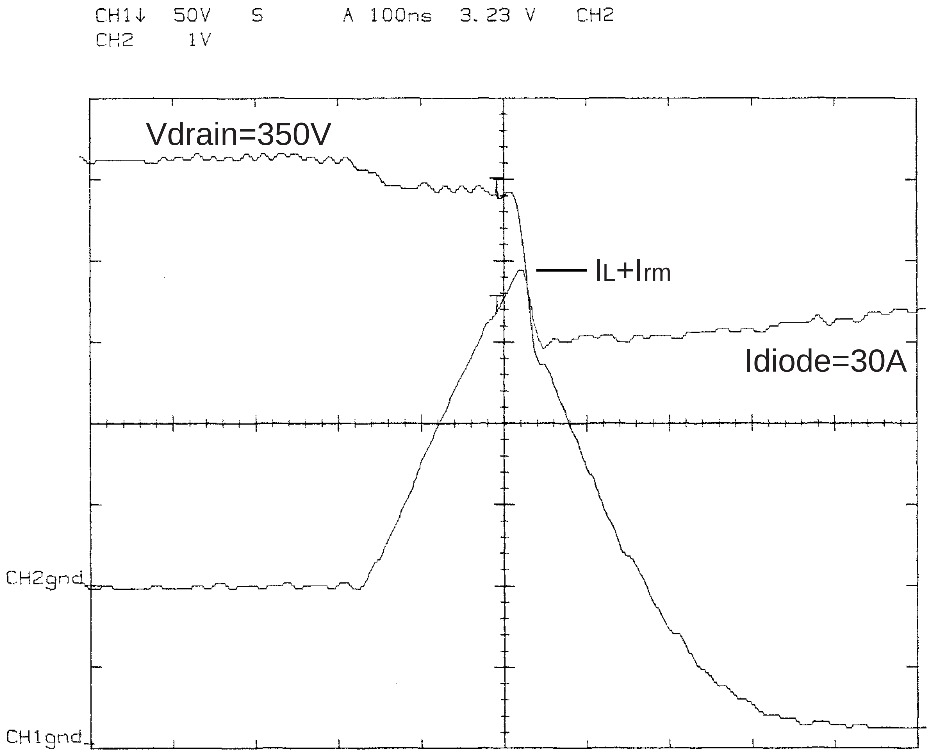
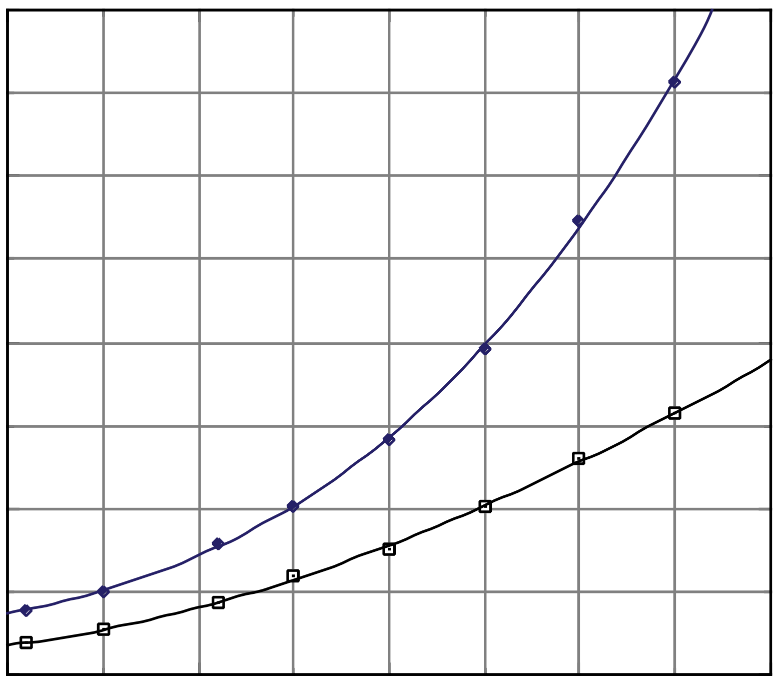


Figure 11. Brand A



Inductor Current, Amps

Figure 12. Total Turn-off Energy Losses versus Inductor Current

problems in the control circuitry or will result in problems meeting FCC specifications for radiated EMI. The ringing may become excessive to the point where avalanche of the diode results. Boost diode avalanche during reverse recovery will cause failure of the boost diode.

Figure 7 shows an APT30D60B FRED (30 Amps, 600 Volts) operating at a forward current of 30 Amps and 350 Volts reverse voltage and being recovered at a 400 Amps/µsec rate. This would be equivalent to a PFC circuit operating 1.5 KW at 85 V_{rms} or 4.5 KW at 200 V_{rms}. Note the waveforms are free from ringing and voltage overshoot.

Figure 8 shows the performance of a competitor's (30 Amp, 600 Volt) FRED, Brand A, operated in the same circuit under the same conditions. Note the snappy recovery and resulting ringing and voltage overshoot. To reduce the ringing and voltage overshoot to an acceptable level, it was necessary to reduce the recovery rate to 220 Amps/µsec, increasing the switching energy losses (Figure 9).

Comparing the MOSFET turn-on switching performance using the APT30D60B, with 400 Amps/µsec commutation; with the Brand A diode, with the 220 Amps/µsec commutation (Figures 10 and 11), shows the circuit with the Brand A diode requires more time to complete the turn-off commutation, thus incurring more loss. The MOSFET turn-off energy losses, at different inductor currents, are plotted (Figure 12) using the two diodes with the appropriate commutation conditions. The circuit with the APT30D60B diode used only half the energy as the circuit with the Brand A diode. Calculating the total turn-off power losses, in a PFC circuit operating at 30 Amps peak inductor current and 100 KHz, using the APT30D60B FRED was 80 Watts versus 155 Watts using the Brand A diode.

Conclusion

The boost diode reverse recovery characteristics have considerable impact on the switching losses of the power MOSFET in a PFC circuit. The snappiness of the boost diode has been shown to be the most important characteristic when EMI is a concern.

1. M. Miller "Differences Between Platinum and Gold-Doped Silicon Power Devices" IEEE Transactions on Electron Devices, Vol. Ed-23, No. 12 December 1996
2. R. Locher and J. Bendal "Minimize Diode Recovery Losses and EMI in PFC Boost Converters" PCIM February 1993

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