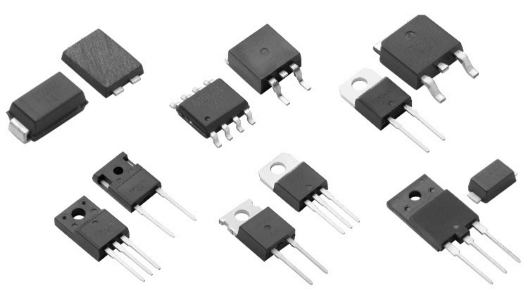
Understanding fast recovery diodes and their uses



An overview: What are fast recovery diodes?

Fast recovery diodes exhibit a much lower reverse recovery time (t_{rr}) than conventional diodes and are typically intended to rectify high frequency switching circuits on the order of tens of kilohertz to hundreds of kilohertz. In other words, these diodes can be turned off quickly.

Eaton offers a diverse range of fast recovery diodes with low V_F and fast t_{rr} to help designers realize low power loss and fast- response circuits. Eaton's ultrafast recovery diodes cover a wide voltage range from 200 V to 800 V with current ratings from 1 A to 75 A. This portfolio of Eaton rectifiers are offered in industry standard packages - namely SMA, SMC,TO220,TO247 , TO252, TO263 and TO3P(F).

The issue of reverse recovery time

In order to understand the issue of reverse recovery time (t_{rr}), it is important to understand how turn-on and turn-off impact a diode.

Forward and reverse bias

Diodes are two-terminal devices that will ideally pass current in one direction and block current in the other direction. This, of course, is not the case in reality (**Figure 1**). When the voltage across the diode is greater than zero, it will be forward-biased. In forward bias, the current is exponentially related to the voltage across the diode.

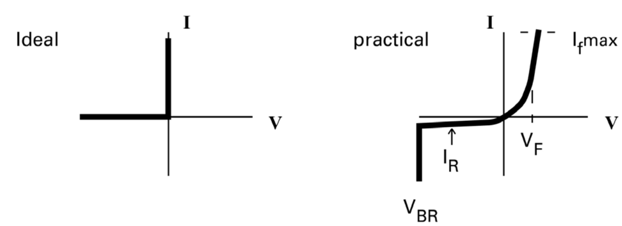


Figure 1: Ideal and practical I-V curves of a diode.

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In reverse bias, the diode will still allow a negligible amount of current to pass through. The uni-directional flow of current in a diode can be utilized for the purpose of voltage rectification.

Response to high frequency switching

As the frequency increases, the turn-on and turn-off characteristics of the diode become of greater importance. When the diode turns on, the reverse bias is transformed into forward bias. Initially, the forward current discharges through the junction capacitance, which is the diode's effective capacitance affected by the width of the depletion layer as the forward voltage changes. Only after this process, the junction starts conducting. As a result, there is a slight delay in reaching the steady-state V_F (forward voltage), but this delay is usually insignificant, even in high-frequency switching scenarios.

However, the turn-off time will be much slower. This is because the reverse voltage must move all the conducting charge carriers out of the junction prior to conduction. This process will take a certain amount of time during which the current continues (I_R). This is known as reverse recovery time (t_{rr}), and it is directly related to both the forward current before reverse voltage is applied and to the rate of change of current (di/dt) at turn-off (**Figure 2**). As switching speed increases, this parameter will impact power dissipation much more greatly. Conventional rectifiers will have a standard recovery time on the order of tens of microseconds, while fast- and ultra-fast recovery diodes will bring that down to the tens of nanoseconds.

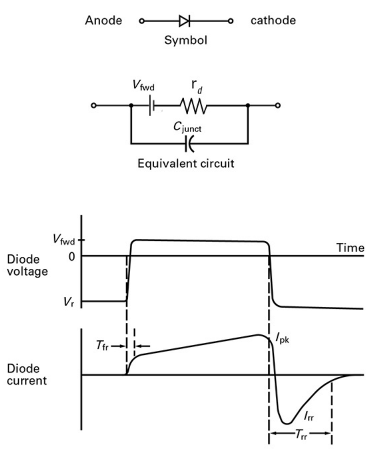

Figure 2: Diode forward and reverse recovery.

The importance of a soft recovery

Fast recovery diodes greatly shorten the recovery time, mitigating power losses on high-frequency switching topologies. However, this requires a much more “aggressive” di/dt and as a result, it is a source of electromagnetic interference (EMI) (**Figure 3**). A fast recovery diode with a soft recovery characteristic exhibits a much gentler turn-off, thereby mitigating this unwanted side-effect. This should still be a consideration for designers as these circuits could generate unwanted harmonics that could interfere with nearby circuits.

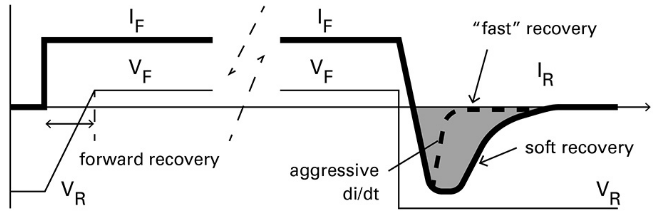

Figure 3: The faster di/dt can cause unwanted EMI that is largely sidestepped by softening the recovery characteristic.

What are fast recovery diodes used for?

As switching frequencies of modern power circuits increase, so do their power losses associated with reverse recovery time (V_R*I). At some point, the proportion of losses from the conventional diode’s t_{rr} becomes unacceptably large. To address, fast recovery diodes can be used to reduce this power loss and are mainly used for high frequency rectification in applications such as motor drivers, and welding machines. They are also used for boost, bootstrap, bypass, free-wheeling, snubbing, and resonance circuits.

The benefits of Eaton’s fast recovery diodes (FRDs) and fast recovery epitaxial diodes (FREDs) are summarized below:

- Fast recovery time less than 50 ns
- Diverse product portfolio
- Low reverse leakage current
- Ultrafast recovery time and soft recovery characteristics
- Low recovery loss

Comparing different diodes based on recovery time

Fast recovery diodes themselves can be categorized into fast recovery diodes and ultra-fast recovery diodes. Many ultra-fast diodes have the additional consideration of an abrupt change in current to lessen t_{rr}. As stated earlier, this will add noise to the system and could possibly require additional components to mitigate EMI.

Schottky barrier diodes are majority carrier diodes with a metal-semiconductor junction instead of the typical p-n junction that can be switched extremely fast. The reverse current in this diode is due to the charging of metal and silicon junction capacitance; this, however, is temperature independent. Moreover, the low forward voltage ensures much more efficient operation than its p-n junction counterparts. At first glance, this would make them more ideal than a faster p-n junction diode; however, these diodes have the additional consideration of their relatively low blocking voltages that generally do not go beyond 100 volts (**Table 1**). This makes these devices more appropriate for use in lower output voltage switch-mode power supplies or, for an RF/microwave mixer circuit. Fast recovery diodes are necessary in applications where the low reverse breakdown voltage of the Schottky barrier diode becomes a hindrance.

	Conventional Diode	Schottky barrier diode	Eaton's FRED & FRD	Ultra-fast recovery diode
Forward voltage (V_F)	1.2 to 1.4 V	0.4 V to 0.6 V	1.2 to 1.4 V	0.9 V to 1.0 V
Reverse recovery time (t_{rr})	Minority carrier charge storage effects limit speed (< 10 µs)	No minority carriers, no charge storage, high speed (< 10 ns)	Minimal stored charge in the pn-junction (< 50 ns)	Minimal stored charge in the pn-junction (25 to 100 ns)
DC blocking voltage (V_R)	50 V to 1000 V	20 to 200 V	Up to 800 V	
Reverse leakage current (I_R)	Low	High	Low	
t_{rr} characteristic	Soft	Soft	Soft	Abrupt
Applications	50-60Hz rectifiers on inputs of off-line switching regulators	Within switching power supplies, low voltage, high current output	Within switching power supplies, low to high current, high voltage output	

Table 1: Comparing diode technologies.

The general uses of the various diodes in a switched mode power supply can be seen in **Figure 4**. The conventional rectifier diodes can be used in the full-wave rectification stage as diode bridge rectifiers. Fast recovery diodes will be in the high voltage and high frequency switching found before the step-down transformer. Finally, Schottky barrier diodes can then be employed on the lower voltage, secondary side of the power supply.

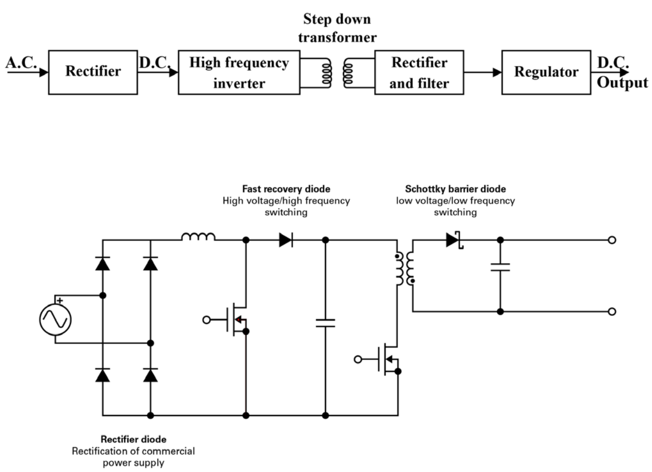

Figure 4: Block diagram and example circuit of a switching mode power supply along with suggested use of different types of diodes at various power supply stages.

FRD and FRED use case in switch-mode power supply

The FRD and FRED can be used in the power correction circuit in a continuous conduction mode (CCM) boost converter for active power factor correction (PFC) (**Figure 5**). After the bridge rectifier, the MOSFET is controlled by a microcontroller using PWM.When MOSFET is on, current flows through the inductor which stores the energy as magnetic field. When MOSFET is turned off, the stored energy from the inductor is released and flows to the capacitor through the diode. In this topology, the inductor current never falls to zero during the entire switching cycle (both on and off), and the MOSFET instead turns on before the inductor current ever reaches zero. This is why this topology is known as continuous conduction mode (CCM).

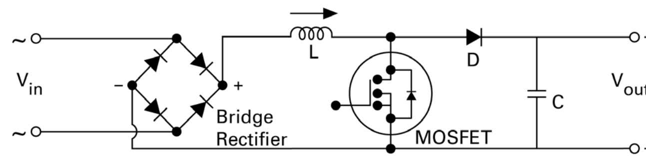

Figure 5: Typical boost converter topology for active PFC.

In the CCM topology, the diode will produce considerable reverse-recovery related losses as it undergoes hard commutation. The diode's reverse recovery current will combine with the inductor's current to greatly increase the MOSFET's turn-on losses. This will result in power loss so the reverse recovery period must be kept as short as possible.

Final notes

Fast recovery diodes are a necessity in high voltage applications where t_{rr} should be kept to a minimum. Eaton's FRD and FRED greatly shorten t_{rr} while maintaining a soft recovery characteristic to limit EMI. The wide voltage range, high current rating, and array of packages allow designers to employ the FRD and FRED ultrafast recovery diodes in their high current, high voltage switching design with relative ease. Eaton's ultrafast recovery rectifiers are suitable for use in all segments, including industrial, energy, consumer, computing and telecommunication applications.

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