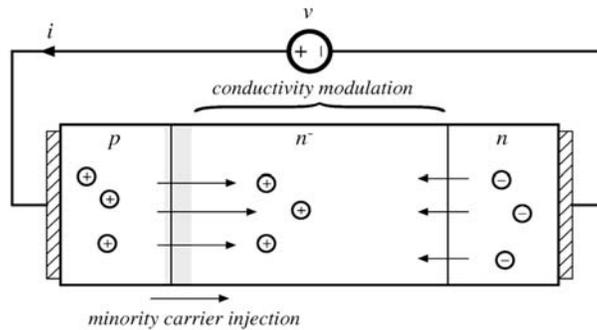


Forward Biased Diode



Minority carrier devices:
 + Conductivity modulation: \uparrow current \Rightarrow \uparrow # of minority carriers
 - it takes time to move charges
 - minority charges must be removed before diode can become reverse biased!

Diode Stored Charge

The diode equation:

$$q(t) = Q_0(e^{\lambda v(t)} - 1)$$

Charge control equation:

$$\frac{dq(t)}{dt} = i(t) - \frac{q(t)}{\tau_L}$$

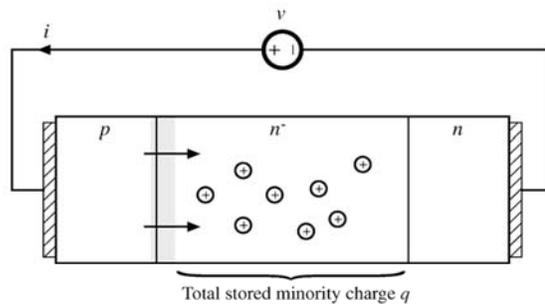
With:

$$\lambda = \frac{1}{\tau} = \frac{q}{kT}$$

$\lambda = 1/(26 \text{ mV})$ at 300 K

τ_L = minority carrier lifetime

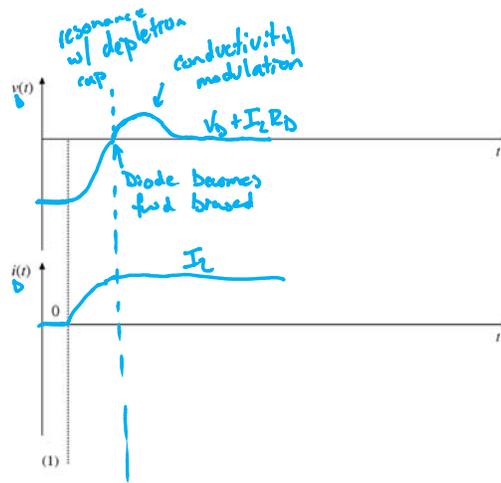
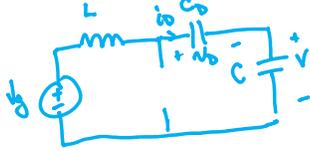
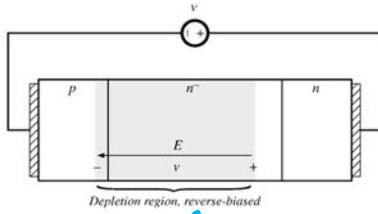
(above equations don't include current that charges depletion region capacitance)
~ms for lightly doped material



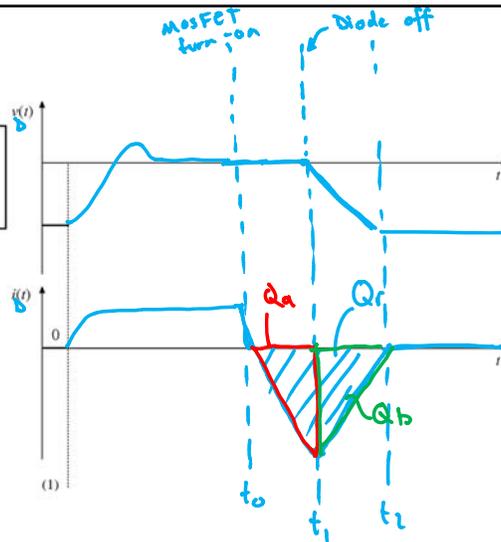
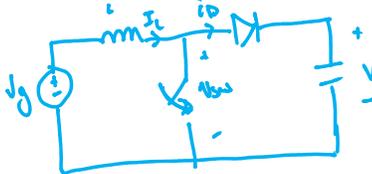
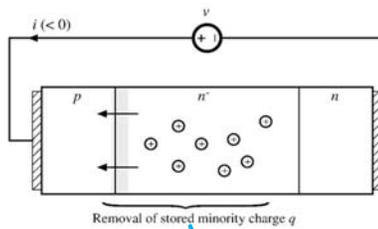
In equilibrium: $dq/dt = 0$, and hence

$$i(t) = \frac{q(t)}{\tau_L} = \frac{Q_0}{\tau_L} (e^{\lambda v(t)} - 1) = I_0 (e^{\lambda v(t)} - 1)$$

Diode Turn-On



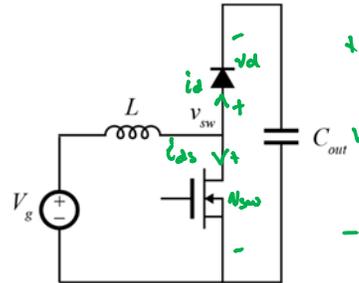
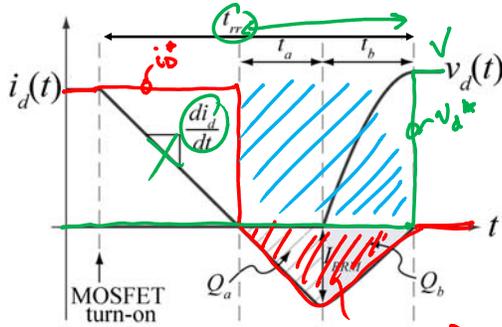
Diode Turn-Off



$Q_A \rightarrow$ removing minority charge
 $Q_B \rightarrow$ depletion capacitance

Diode Reverse Recovery

Approximation



$Q_a + Q_b = Q_r$
 Energy loss shows up in MOSFET turn-off
 $E = \int i_{ds} v_{sw} dt = V (I_L t_{rr} + Q_r)$
 $P_{sw,rr} = V (I_L t_{rr} + Q_r) f_s$



Datasheet RR Characteristics

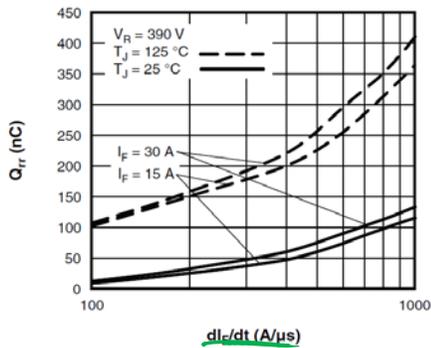


Fig. 10 - Typical Stored Charge vs. di_F/dt

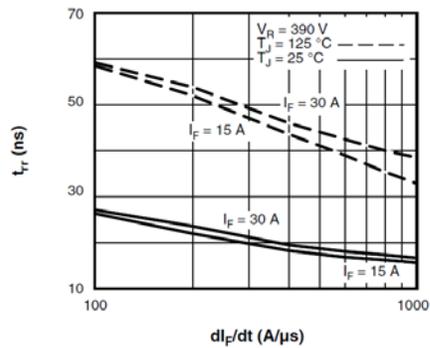


Fig. 9 - Typical Reverse Recovery Time vs. di_F/dt



Types of Power Diodes

*p-n
power
diode*

Standard recovery

Reverse recovery time not specified, intended for 50/60Hz

Fast recovery and ultra-fast recovery

Reverse recovery time and recovered charge specified
Intended for converter applications

Schottky diode

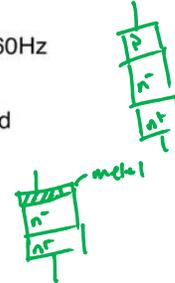
A majority carrier device

Essentially no recovered charge

Model with equilibrium $i-v$ characteristic, in parallel with depletion region capacitance

Restricted to low voltage (few devices can block 100V or more)

SiC Schottky diodes → 600-1.2kV



Paralleling Diodes

Attempts to parallel diodes, and share the current so that $i_1 = i_2 = i/2$, generally don't work.

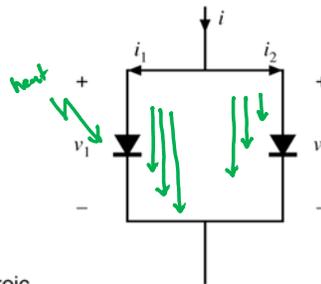
Reason: thermal instability caused by temperature dependence of the diode equation.

Increased temperature leads to increased current, or reduced voltage.

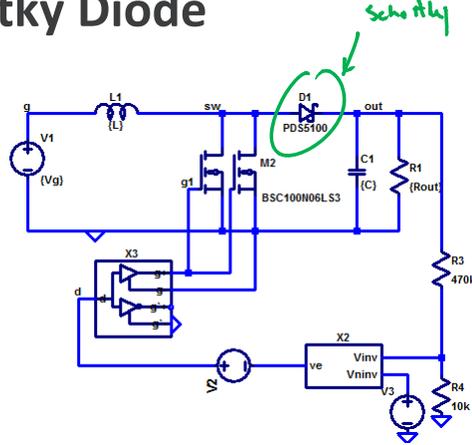
One diode will hog the current.

To get the diodes to share the current, heroic measures are required:

- Select matched devices
- Package on common thermal substrate
- Build external circuitry that forces the currents to balance



Schottky Diode

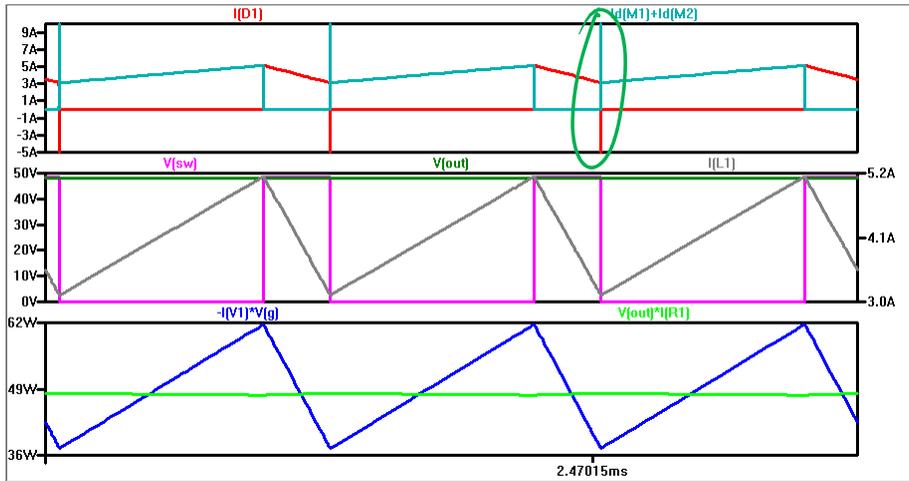


L	C _{out}	f _s	Diode	η (Sim)
22uH	22uF	202k	Si (FR)	93.9%
22uH	22uF	202k	Si Schottky	96.9%

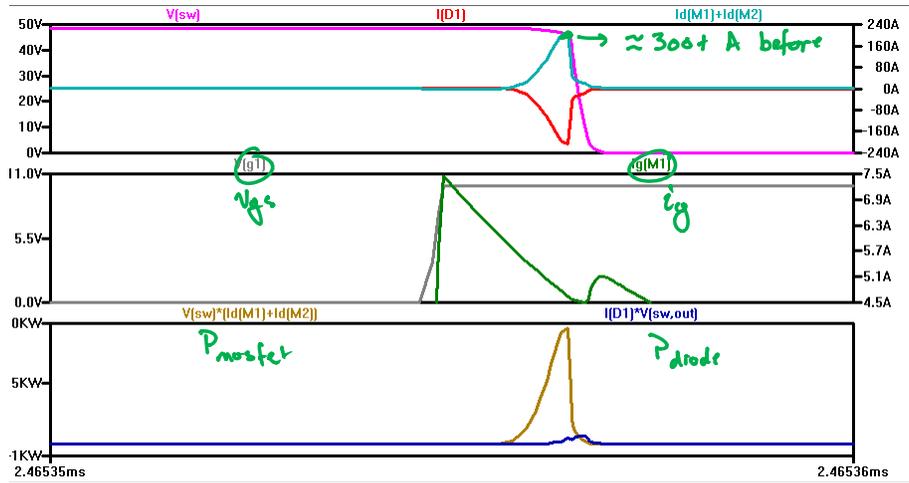
→ close to 97.6%



Simulation Waveforms



Switching Transition



Power MOSFET \rightarrow vertical devices

