IGBT reverse conduction characteristics
Hard-switching and soft-switching

Energy Saving Products BU
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International Rectifier

The IGBT in reverse

The IGBT is a four-layer structure (P-N-P-N).
It has a well-defined blocking capability in one direction and a weak and undefined blocking capability in the reverse direction.

The MOSFET is a three-layer structure (N-P-N) with good reverse conduction capabilities.
For more details follow the link below to appnote AN-983, Section 1, AN-983

IGBTs in topologies with reverse conducting requirements (bridge) need an anti-parallel diode, normally co-packaged with the IGBT.
Single-ended topologies (boost PFC) do not require an anti-parallel diode.

A series blocking diode must be added to IGBTs (and FETs) if the topology requires reverse blocking capability (current-fed converters).

Advantages and disadvantages compared to a MOSFET

The diode co-packaged with the IGBT is targeted to the application.

The MOSFET integral rectifier has a low voltage drop but reverse recovery characteristics are inadequate for high frequency applications.

IR co-packages three different types of diodes targeted to the application:

- Very low voltage drop for resonant and ZVS converters to minimize diode conduction losses
- Very soft recovery for motor drives to minimize EMI
- Very low stored charge for high frequency applications to minimize recovery and turn-on losses

Soft-switching v. Hard-switching

Soft-switching

The diode co-packaged with the IGBT conducts *before* the IGBT turns on, on account of the resonant nature of the load.

When the IGBT turns on, it has only a diode drop between emitter and collector.

The turn-on losses are virtually zero. See example in next page.

This allows operation at higher frequency.

Application examples: induction heating and some power converters.

Hard-switching

When the IGBT turns on load current is flowing in the antiparallel diode of a *complementary* IGBT.

At turn-on the IGBT picks up the load current plus the reverse recovery current of the diode. See waveform later.

Because of the reverse recovery of the diode turn-on losses are normally higher than turn-off losses.

Most power converters and motor drives operate in this mode.

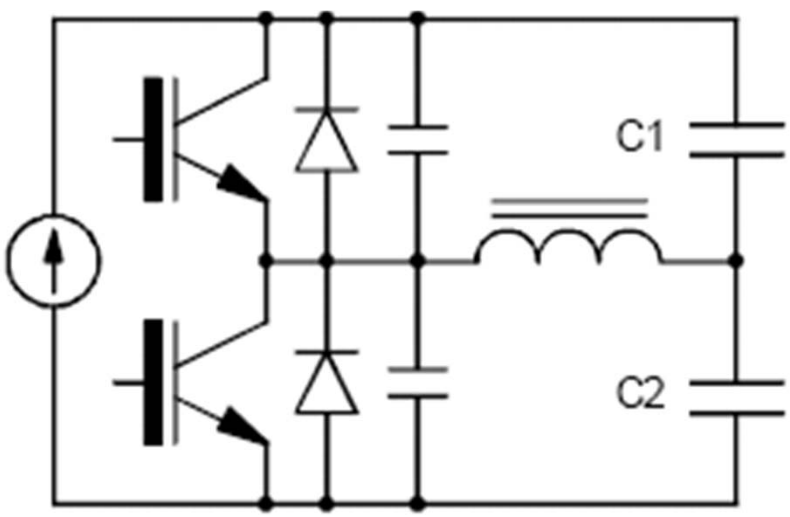
Soft-switching example

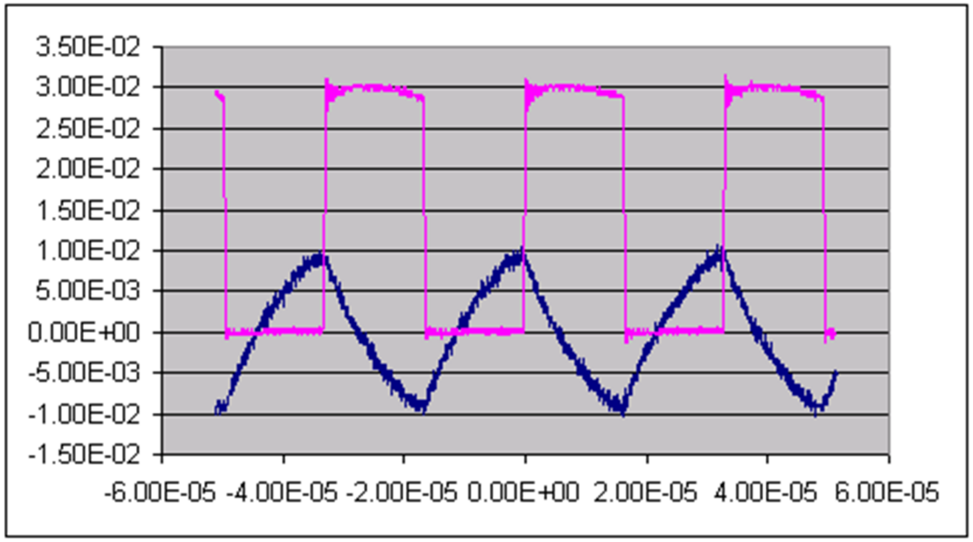
Series Resonant Half-bridge converter (SRHB)

The pink trace is the voltage at the midpoint. The blue trace is the current in a switch.

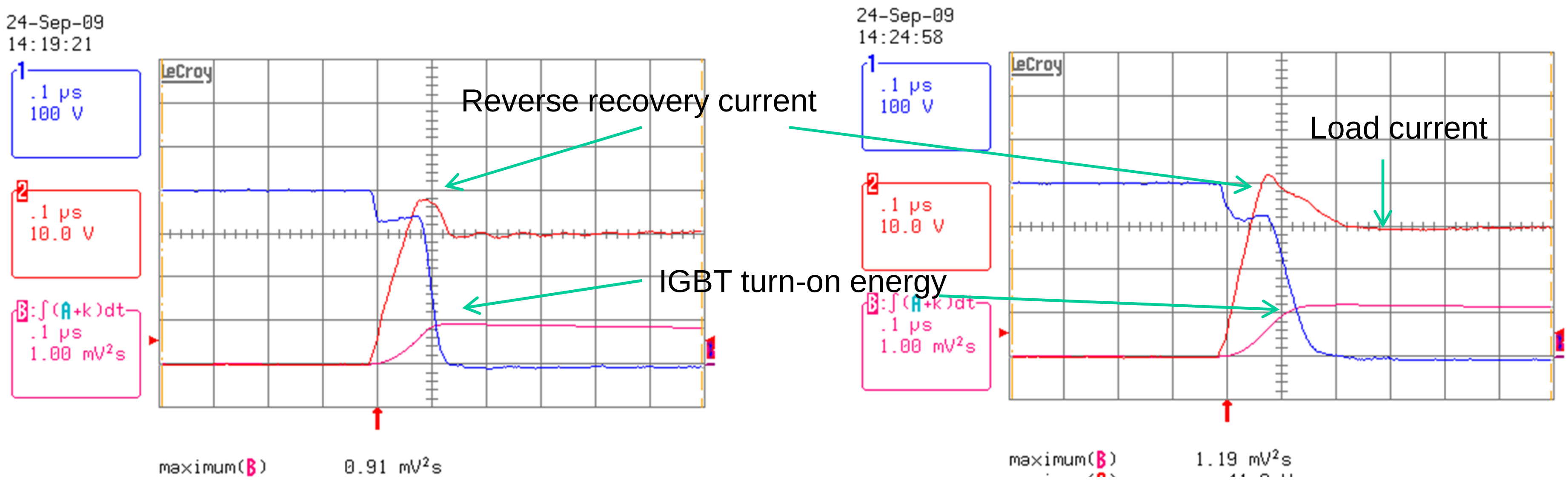
Diode has no reverse recovery losses because load current transfers from the diode to the antiparallel IGBT with a very low di/dt <10A/µs (ZVS). During the diode reverse recovery load current flows in the IGBT and in the diode (as reverse recovery current). T_{RR} is normally <1µs in these operating conditions

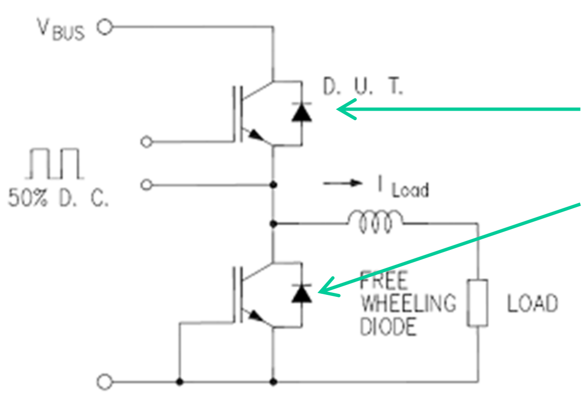
Diode V_{FR} is the important parameter. A large diode V_{FR} increases losses





Hard-switching example





When the D.U.T turns on, load current transfers:

- to IGBT

- from freewheeling diode

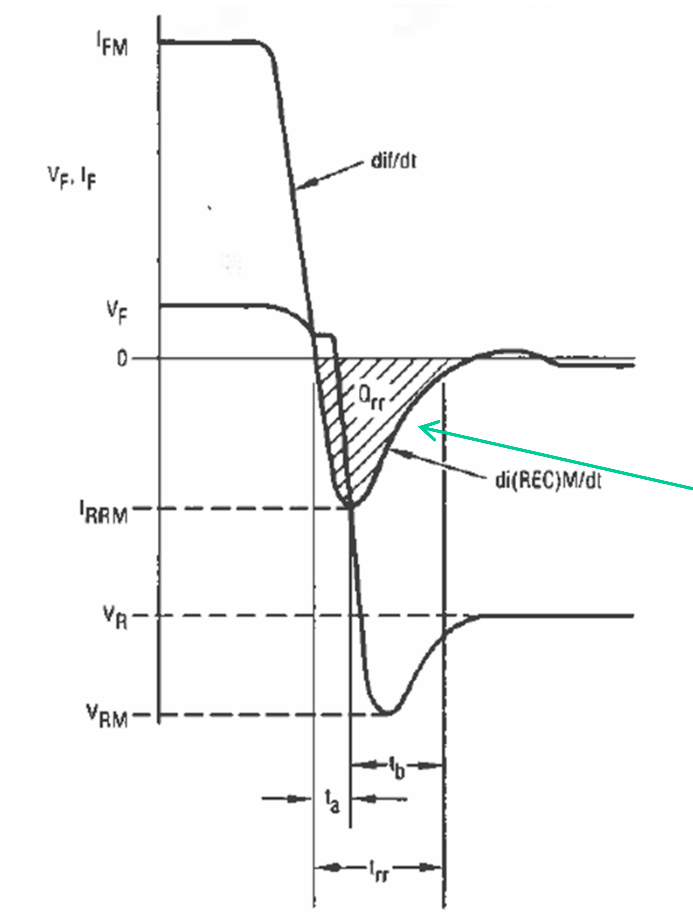
Higher reverse recovery charge means higher IGBT turn-on losses

Diode has its own recovery losses, as well. They can be higher or lower than the IGBT turn-on losses, depending on diode and manufacturer.

Soft recovery v. hard recovery

Di/dt during the second half of the reverse recovery measures "softness"

A diode with high di/dt is called "snappy". Frequently this di/dt is the highest di/dt in the circuit. It induces noise in the logic and generates EMI.



Di/dt during second half of the reverse recovery

Increasing gate drive impedance at turn-on has a small beneficial effect. It normally increases turn-on losses.

Very few manufacturers provide data on "softness"