Introduction to Soft Switching

- Why soft switching
- Types of soft switching
- Examples

Why Soft Switching?

- Hard switching losses
Why Soft Switching?

- Diode reverse recovery problem in all topologies

Magnetics size

- Hager switching frequency reduce size of other components
Switching Losses

Conceptual

Soft Switching Terminology

Hard Switching

ZVS

Pseudo

ZCS

True

Pseudo

True
Soft Switching Methods

- Passive Lossless Snubbers
- Quasi resonant switching
- Auxiliary switch, lossless snubber
- Self soft switching topologies (multi transistor)
- Operation at DCM or DCM-CCM borderline
- Resonant converters

Passive Lossless Snubber

- No additional switches
Controlling $dI/dt$

- "Turn on" snubber
- Series inductor
- Need to recover energy

Controlling $dV/dt$

- Turn off" snubber
- Parallel capacitor
- Need to recover energy
Recovery by Resonant Circuit

- Resonant process is “Lossless”

Example 1

- “turn off” snubber
Example 1

• dV/dt is controlled

Example 1

• Energy is returned to supply
Snubber Seminar on WEB

http://www.ee.bgu.ac.il/~pel/public.htm#4

S. Ben-Yaakov and G. Ivensky,
Passive lossless snubbers for high frequency PWM converters.
IEEE Applied Power Electronics conference,
APEC-99, Dallas, 1999.

Old Snubber
Quasi-Resonant (Resoant Transition)

- Applies resonant phenomena during transitions
- Normally no special energy-return paths
- May use extra passive components or just original circuit
- Variable switching frequency operation
Quasi-Resonant

- $L_r, C_r$, form a resonant circuit
- Resonant time is fixed; variable switching frequency
- High conduction losses

Flyback in DCM

- Turn on may be under high voltage
- $CV^2/2$ losses
- Lower losses if “turn on” at valley
"Quasi-Resonant"
Flyback in DCM

- Resonant at primary side
- Variable switching frequency
- Lower EMI (?)

Figure 1. Basic Quasi Resonant Converter Using KA40-series (Color TV Application)

Figure 4. The Typical Waveform of MOSFET Drain Voltage for Quasi Resonant Converter
Auxiliary Switch

![Diagram of Auxiliary Switch]

<table>
<thead>
<tr>
<th>Transistor or diode</th>
<th>Turn-on</th>
<th>Turn-off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q₁</td>
<td>ZCS</td>
<td>ZCS and ZVS</td>
</tr>
<tr>
<td>Q₂</td>
<td>ZCS</td>
<td>ZCS and ZVS</td>
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<tr>
<td>D₂</td>
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</tbody>
</table>

Table 2. Switching conditions of the transistors and diodes.
Auxiliary Switch

Self Soft-Switching (Multi Switch)

- Current polarity reversal is a must
- \( C_1, C_2 \) of transistor plus external (if any)
Asymmetrical Half Bridge DC-DC Converter

Current polarity reversal is a must
What is the purpose of $C_c$?

Dead time requirement
Phase Shifted PWM

ZVS of main switches

Basic Phase Shifted PWM Stage

Phase Shifted PWM

Stage 1 - Pewering
Phase Shifted PWM

Stage 2 - Power to \( t_{\text{off}} \) transition - capacitor charge

Phase Shifted PWM

Stage 3 - Power to \( t_{\text{off}} \) transition - Diode catch

- Two diodes are conducting during \( T_{\text{off}} \)
**CCM-BCM operation**

- Soft switching requires current polarity reversal
- Synchronous Buck in CCM: Upper transistor hard switched
- Operation just below CCM-DCM border will facilitate ZVS
- Higher conduction losses

**Resonant Converters**

- Sinusoidal Current due to resonance
- Soft switching achievable
Resonant Converters

- Sinusoidal Current due to resonance
- Soft switching achievable