LLC Resonant Half Bridge Converter
Design Consideration

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1. Introduction

- Growing demand for higher power density and low profile in power converter has forced to increase switching frequency
- However, **Switching Loss** has been an obstacle to high frequency operation

1.1 What is soft switching?

- **Hard switching**
  - Overlap of voltage and current
  - Capacitive loss
  - Reverse recovery loss

- **Zero-voltage-switching (ZVS)**
  - Turn on while switch voltage ($V_{ds}$) is zero by flowing current through the anti parallel diode

[ The ideal zero-voltage soft switching ]

[ Switching loss of a switch during switching interval ]
1.2 Soft Switching Operation

- Resonant converter: processes power in a sinusoidal manner and the switching devices are softly commutated
  - Voltage across the switch drops to zero before switch turns on (ZVS)
    - Remove overlap area between V and I when turning on
    - Capacitive loss is eliminated

- Series resonant converter / Parallel resonant converter

![Resonant Circuit Diagram]

2. Resonant Converter Overview

Series Resonant (SR) converter

- The resonant inductor (Lr) and resonant capacitor (Cr) are in series
- The resonant capacitor is in series with the load
  - The resonant tank and the load act as a voltage divider → DC gain is always lower than 1 (maximum gain happens at the resonant frequency)
  - The impedance of resonant tank can be changed by varying the frequency of driving voltage (V_d)
Parallel Resonant (PR) converter

- The resonant inductor (Lr) and resonant capacitor (Cr) are in series
- The resonant capacitor is in parallel with the load
  - The impedance of resonant tank can be changed by varying the frequency of driving voltage (V_d)

2.1 Limitation of SRC and PRC resonant

- **Limitation of the conventional SRC (Series Resonant Converter)**
  - Can optimize performance at one operating point, but not with wide range of input voltage and load variations (too wide frequency range)
  - Difficult to regulate the output at light or no load condition

- **Limitation of the conventional PRC (Parallel Resonant Converter)**
  - Large amount of circulating current because the load is connected in parallel with the resonant network,
  - Difficult to apply in high power applications.
2.2 LLC Resonant Converter Overview

**LLC resonant converter**
- Topology looks almost same as the conventional LC series resonant converter
- Magnetizing inductance \( L_m \) of the transformer is relatively small and involved in the resonance operation
- Voltage gain is different from that of LC series resonant converter

**Features of LLC resonant converter**
- Reduced switching loss through ZVS: Improved efficiency
- Narrow frequency variation range over wide load range
- Zero voltage switching even at no load condition
- Typically, integrated transformer is used instead of discrete magnetic components
2.2 LLC Resonant Converter Overview

**LLC Resonant converter**

- **Advantages**
  - Reduced switching loss through ZVS → Improved efficiency and EMI
  - Reduced magnetic components size by high frequency operation
  - Narrow frequency variation range over wide load range

- **Drawbacks**
  - Larger circulating current compared to LC resonant converter due to the relatively small magnetizing inductance
  - Difficult to optimize transformer design

![Half-bridge LLC resonant converter diagram](image)

2.3 Integrated Transformer

- **Integrated transformer in LLC resonant converter**
  - Two magnetic components are implemented with a single core (use the primary side leakage inductance as a resonant inductor)
  - One magnetic components (Lr) can be saved
  - Leakage inductance not only exists in the primary side but also in the secondary side
  - Need to consider the leakage inductance in the secondary side

![Integrated transformer diagram](image)
3. LLC Resonant Converter Operation mode

3.1 Operation mode
LLC resonant HB converter

- Q1 is ON, Q2 is OFF
- D1 is ON, D2 is OFF; \( V(D2) = -2 \cdot V_{out} \)
- Ir flows through Q1’s body diode \( \rightarrow \) ZVS Condition
- \( L_m \) is charged with constant voltage

Gain (M)

Below resonance \( f_s < f_o \)
- Larger circulating current
- Soft commutation of rectifier diode

Above resonance \( f_s > f_o \)
- Smaller circulating current
- Hard commutation of rectifier diode
3.2 Operation mode
LLC resonant HB converter

2) \( T_1 - T_2 \)
- Q1 is ON, Q2 is OFF
- D1 and D2 are OFF; \( V(D1) = V(D2) = 0 \)
- Transformer’s secondary is open
- \( I_r = I_m \)
- Energy is taken from \( V_{in} \) and goes to \( V_{out} \)

3.3 Operation mode
LLC resonant HB converter

3) \( T_2 - T_3 \)
- Q1 is ON, Q2 is OFF
- D1 and D2 are OFF; \( V(D1) = V(D2) = 0 \)
- Transformer’s secondary is open
- \( I_r = I_m \)
3.4 Operation mode
LLC resonant HB converter

3) T₁ - T₄

- Q1 and Q2 are OFF (dead-time)
- D1 and D2 are OFF, V(D1)>V(D2)=0
  - transformer’s secondary is open
- (L+Lm) charges Coss of Q1 and discharges Coss of Q2,
  until V(Coss of Q2)=0
- Q2’s body diode starts conducting
- Output energy comes from Co
- Phase ends when Q2 is switched on

4. FSFR series HB Resonant Converter

- PWM / PFM Controller + High side Drive IC + 2 MOSFET in 9-SIP PKG
  - Universal controller: can be applied various topology
  - High-side drive IC: has immunity against switching noise
  - MOSFET with fast recovery body diode \( t_{rr} = 120\,\text{ns} \)

Advantage through system integration
- High reliability & productivity
- BOM cost reduction
- Easy design
4.1 Features of FSFR series

- Variable frequency control with 50% duty cycle for half-bridge resonant converter topology
- High efficiency through zero voltage switching (ZVS) : typ. Eff=93~94% for Vo=24V
- Internal MOSFETs with Fast Recovery Type Body Diode (trr=120ns)
- Internally optimized dead time (fixed. 350ns)
- Up to 300kHz operating frequency
- Pulse skipping for Frequency limit (programmable) at light load condition
- Simple remote ON/OFF control

<table>
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<tr>
<th>Part Number</th>
<th>Package</th>
<th>Recommended Operating Junction Temperature</th>
<th>$R_{D(S,ON,MAX)}$</th>
<th>Maximum Output Power without Heatsink ($V_{IN}=350~400V$)</th>
<th>Maximum Output Power with Heatsink ($V_{IN}=350~400V$)</th>
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<tr>
<td>FSFR2100</td>
<td>9-SIP</td>
<td>-40 to +130°C</td>
<td>0.38Ω</td>
<td>200W</td>
<td>450W</td>
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<tr>
<td>FSFR2000</td>
<td>9-SIP</td>
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<td>0.67Ω</td>
<td>160W</td>
<td>350W</td>
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<td>FSFR4000</td>
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<td>0.85Ω</td>
<td>140W</td>
<td>300W</td>
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<td>0.95Ω</td>
<td>120W</td>
<td>260W</td>
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<td>FSFR1700</td>
<td>9-SIP</td>
<td>-40 to +130°C</td>
<td>1.25Ω</td>
<td>50W</td>
<td>200W</td>
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</tbody>
</table>

4.2 Application circuit for FSFR series

- LLC resonant converter for LCD TV
  - $V_{IN}=350~400V$, $V_{O}=25V$, $I_o=8A$ (200W)
  - Eff=94% at full load
  - No heat sink is required up to 200W
4.3 3KW PSU Application - Block Diagram

Rectifier
Input 100-240Vac
PFC IC
Rectifier

DC-DC Converter
LLC Resonant HB

Output 42V_6.5A

Switching regulator
CXA8038A (SONY)
Resonant mode
DC-DC Converter
FCH25A20 (Nihon Inter)*6EA
2SK3235 (HITACHI)*6EA
KSU20B60 (Nihon Inter)*2EA
D25XB60 (600V 25A)
SHINDENGEN*2EA

PFC controller
FQAF24N50 (FAIRCHILD)*6EA
PFC IC
TK83854 (TOKO)

4.4 350W PSU Application - Block Diagram

Rectifier
Input 100-240Vac
PFC IC
Rectifier

DC-DC Converter
LLC Resonant HB

Output 12V_12A

Switching regulator
CXA8038A (SONY)
Resonant mode
DC-DC Converter
IPP06CN10N (Infineon)*2EA
2SK3313 (TOSHIBA)*2EA

PFC IC
UC3854DW
SPA21N60C3 (Infineon)*1EA
STTH15R 06FP_ST*1EA

Synchronous Rectification
MIP2G4 (Panasonic)*1EA
Flyback
converter
5V 3A STB
FCH10A15 (Nihon Inter)*1EA
Thank you