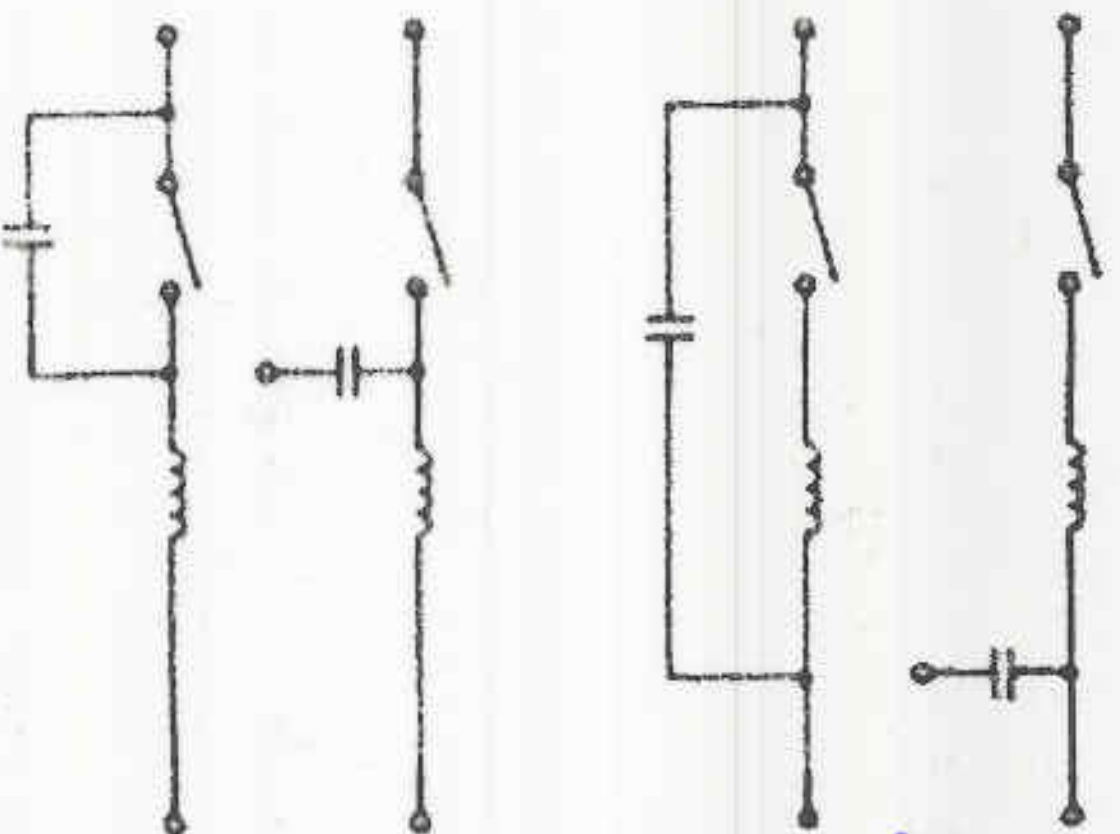
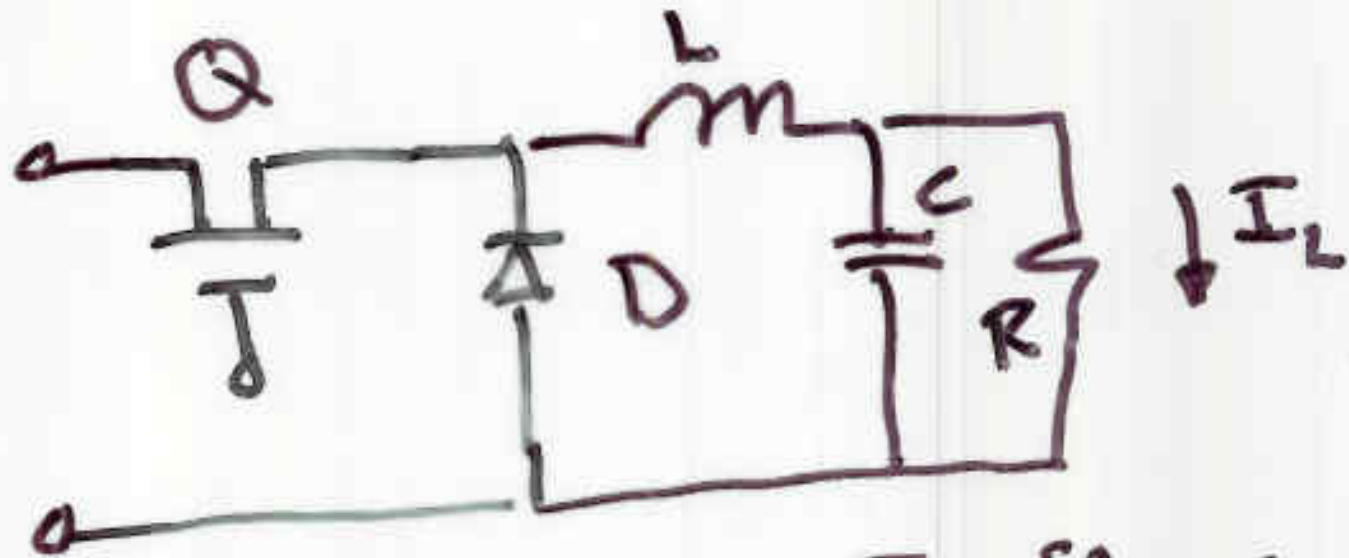




ZERO CURRENT

ZERO VOLTAGE

Fig. 7 - Resonant Switches



- ① if Q off D ON, I_L flows through D
- ② i_D will continue to flow due to Q_{rr} for Δt_{rr} after Q ON
- ③ When Q goes from off to on large E_{off} occurs since V_{DS} large as

force i_Q to be zero as



} ZCT
switching

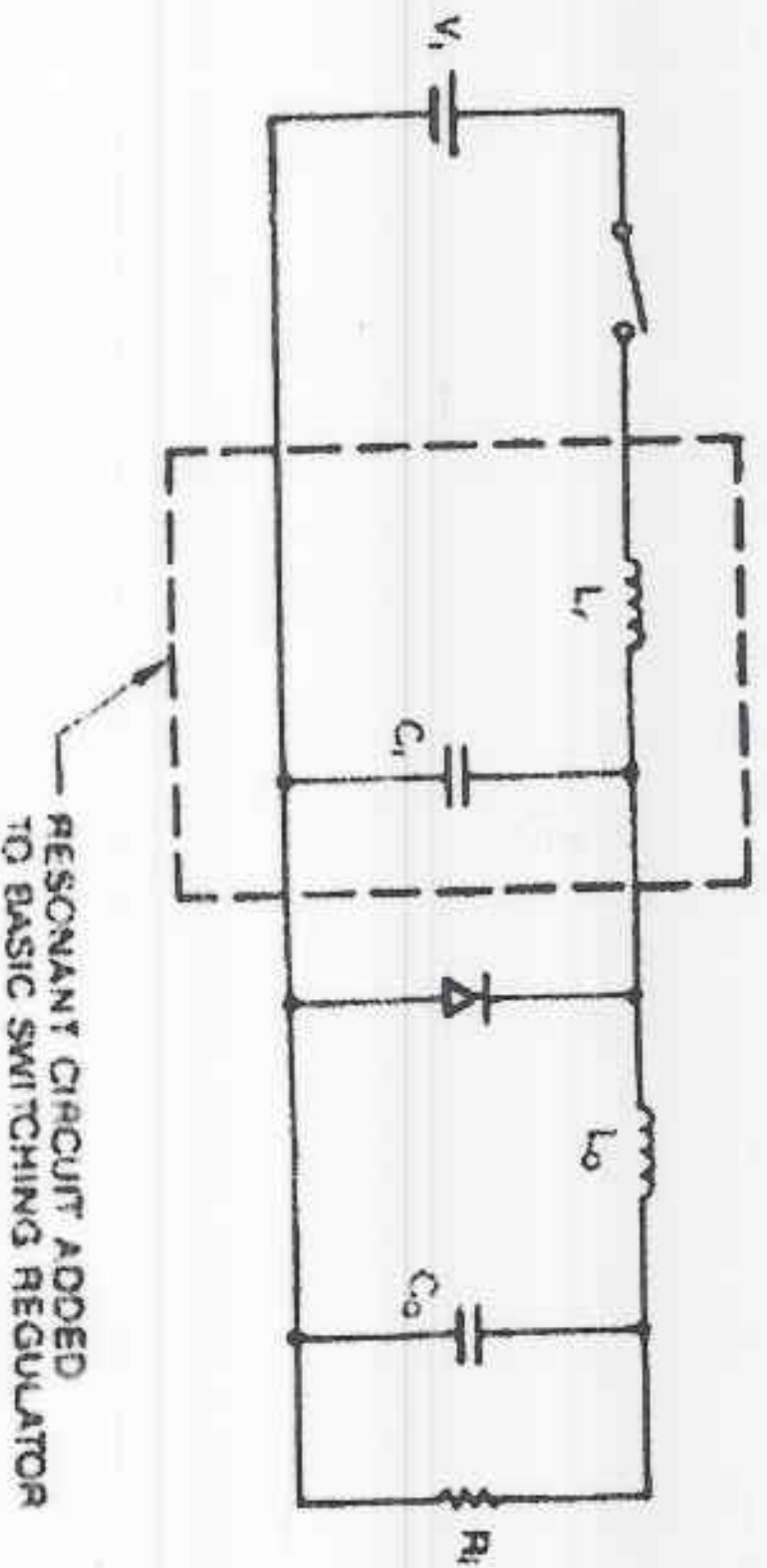


Fig. 3 - (Basic) Resonant Converter

L_r, C_r allow reduction of SW loss
force πC_T

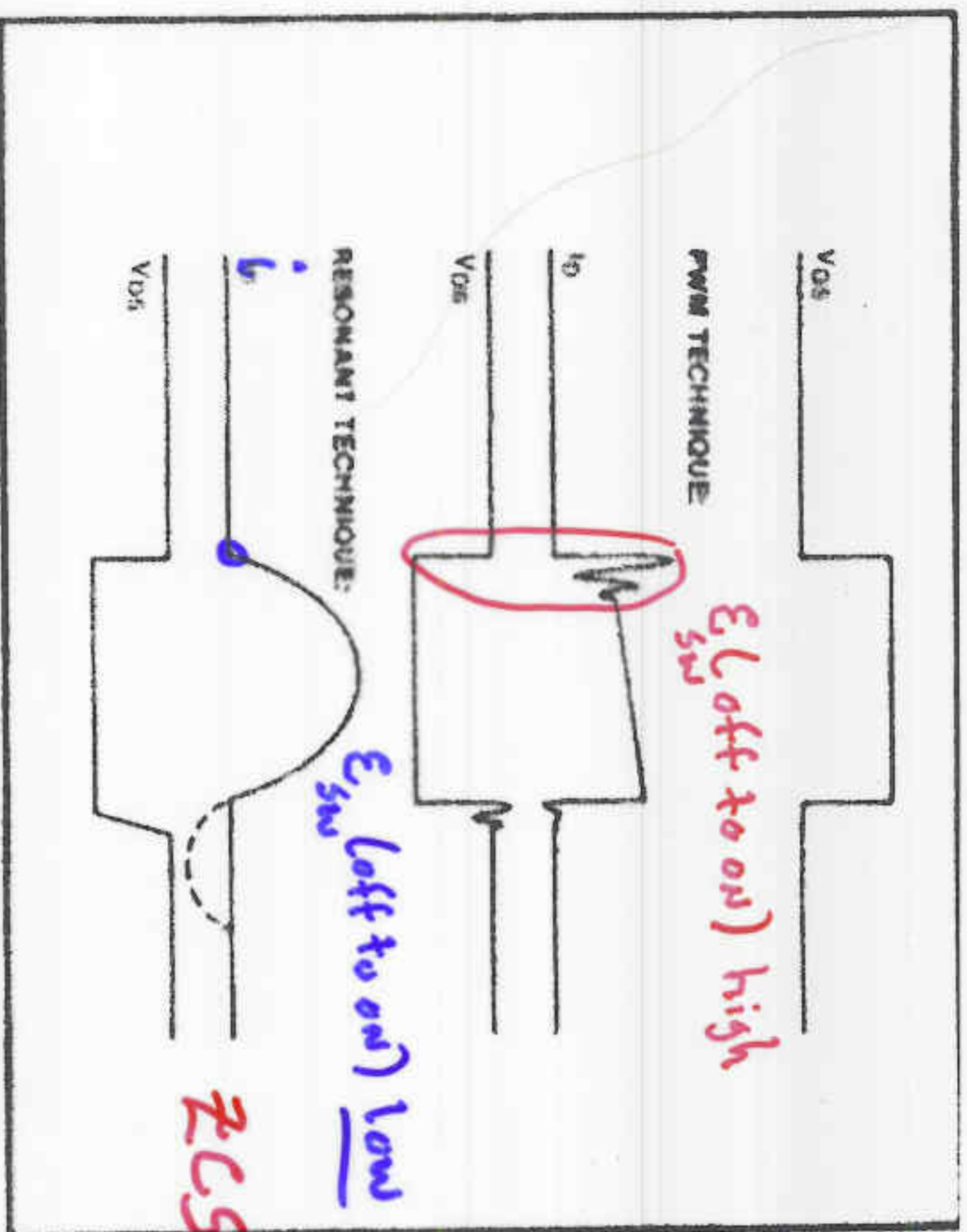


Fig. 5 - PWM vs. Resonant Switching

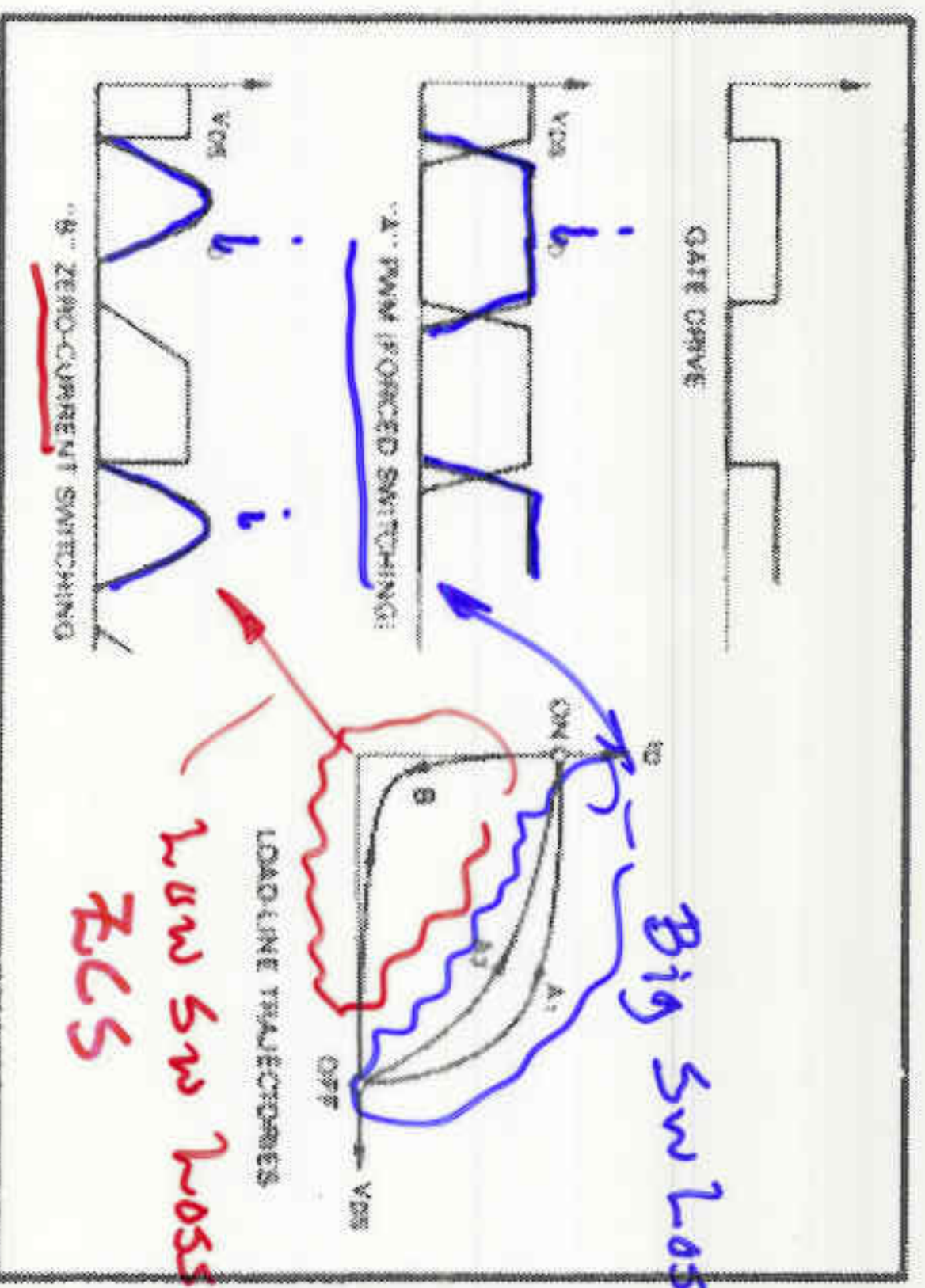
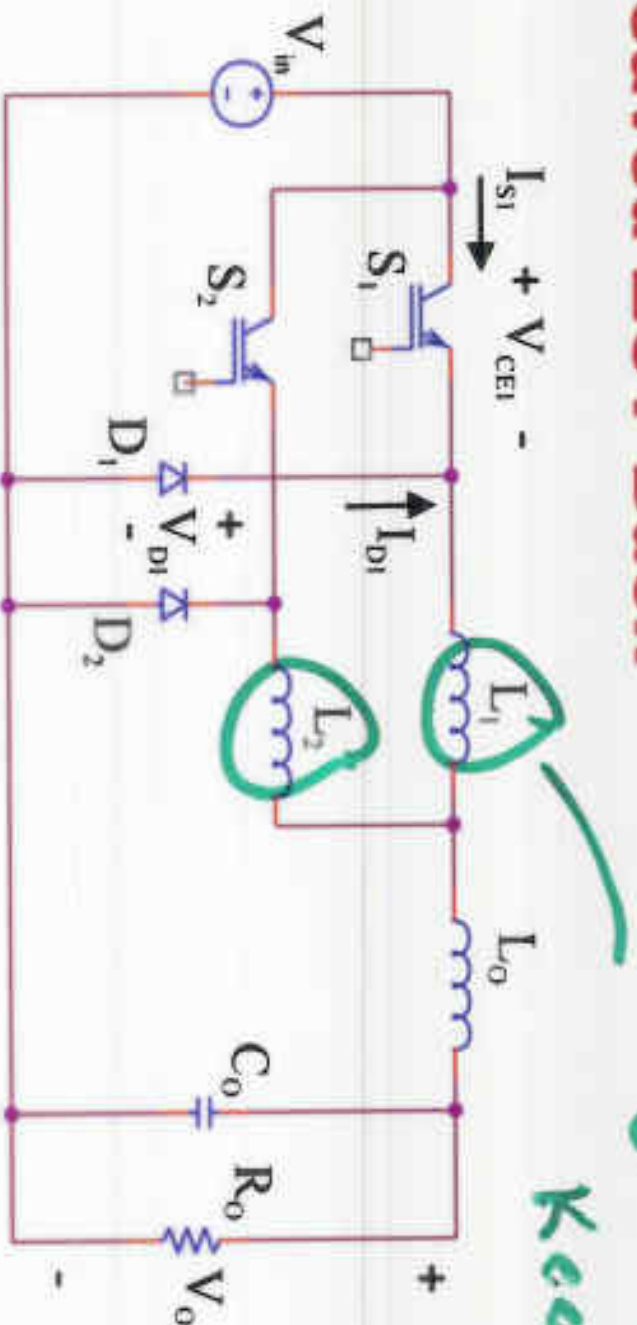


Fig. 6 - Switching Stress and Switching Loss

Interleaved ZCT Buck



lags i_{L1} w.r.t V_{L1}
Keep $i_a = 0$

- Two small inductors (L_1, L_2) added to achieve zero-current-transition turn on of the switches S_1 and S_2
- Out-of-phase operation of S_1 and S_2 , as in two-phase converters
- Significant reduction of losses associated with diode reverse recovery
- Simple operation, no resonant circuit

Comparison of Losses

Powerex: CM150DU-24NFH		Hard switched	New circuit
Turn-on loss	(mJ)	4.0	0.4
Turn off loss	(mJ)	3.8	3.8
Conduction loss (one sw. period)	(mJ)	6.1	6.1
Loss per switch (32 kHz)	(W)	444.2	164.5
Diode recovery loss	(mJ)	12.0	2.0
Diode conduction loss (one sw. per.)	(mJ)	3.5	3.5
Diode loss (32 kHz)	(W)	496.6	88.3
Aux switch, eq (10)* in [2]	(mJ)		
Total loss (32 kHz)	(W)	940.8	505.6

*m=0.6, T₀=3 μs, k=2, V_c=10 V

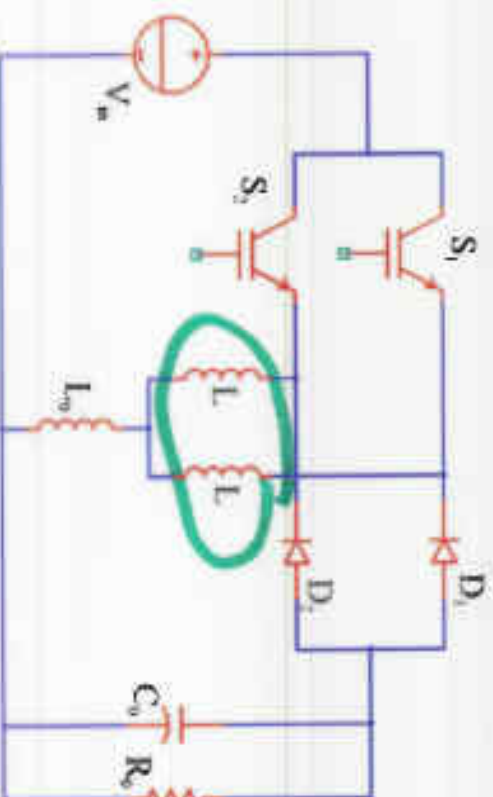
— 10x

— NO advantage

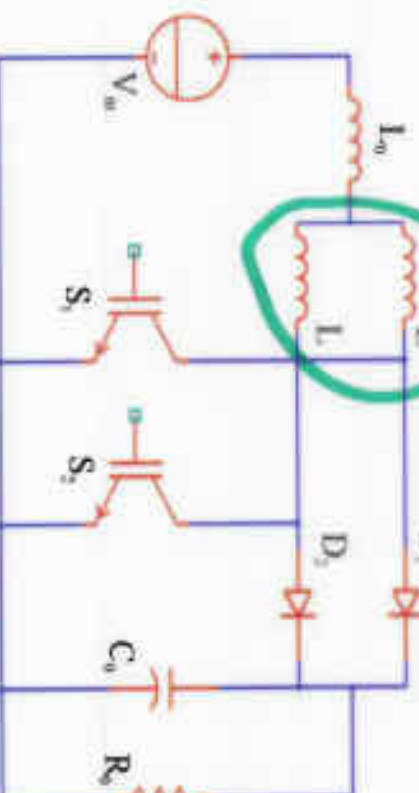
— 6x

— 2x better overall

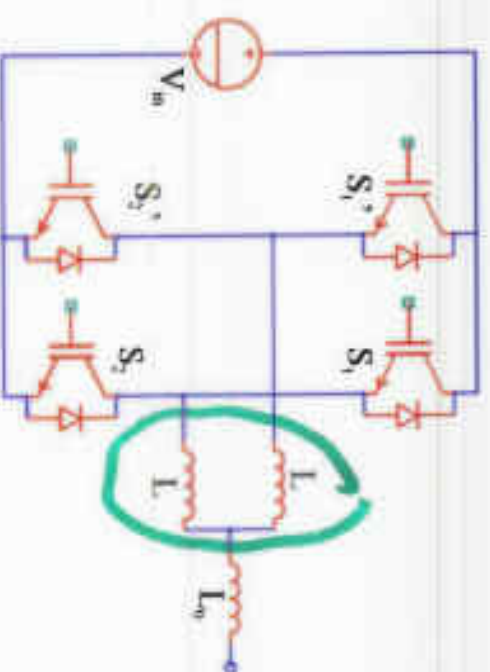
Examples of Other Interleaved ZCT Converters



Buck-boost



Boost



One leg of an
interleaved ZCT bridge
or three-phase inverter

Basic Concept
ZVS

To go from
FET off to
FET on

V_{rail}

Q

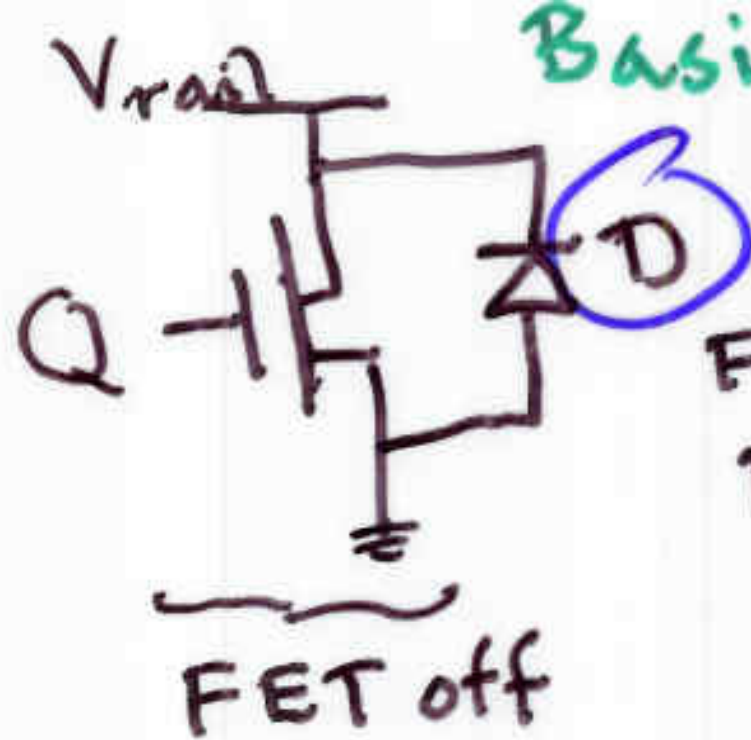
D

FET off

V

I_D

The diagram shows a MOSFET circuit with a drain inductor and a diode. The MOSFET is labeled 'Q' and the diode is labeled 'D'. The drain is connected to a rail voltage V_{rail} through an inductor. The source is connected to ground. A bracket under the MOSFET is labeled 'FET off'. To the right, a graph shows the drain voltage V (black line) and drain current I_D (blue line) over time. The voltage V starts at V_{rail} and drops to zero when the MOSFET turns on. The current I_D starts at zero and rises when the MOSFET turns on.



To go from
FET off to
FET on



$[V I_{on} \Delta t]$
 $\epsilon_{off} \rightarrow 0$

$$P_{off\ ON} = f_{sw} [E_{off\ ON}]$$

ON

if D is placed on ahead
of Q by a leading i

$V_G = 0$ during

FET
diode

I_{ON}

0

$$\epsilon_{\text{off}} \rightarrow 0$$

IGBT

MOSFET

ADVANTAGES:

1. ZERO CURRENT SWITCHING
2. LOW COMPONENT STRESS
3. LOW EMI
4. USEFUL PARASITIC ELEMENTS
5. IMPROVED DIODE RECOVERY

$ZVS + 00$

Use L parasitic)

Losses ↓

DISADVANTAGES:

1. GREATER COMPLEXITY
2. HIGHER PEAK CURRENTS
3. NEW TECHNOLOGY LEARNING CURVE

What?

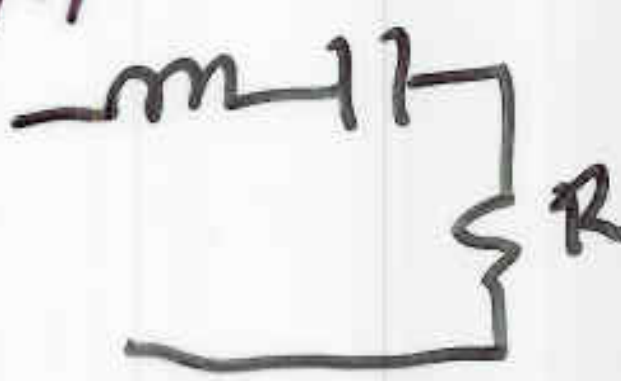
5W stress

QTI

Fig. 4 - Resonant Converter Advantages

$$f_{5W} = \frac{f_R}{n} \quad 1, 3, \dots$$

□-wave excitation



$$V_0^R / V_{IN} (@ R)$$



unique to W-wave excitation

$$V_0 / V_{IN} \text{ across } C \quad \frac{V_0^C}{V_{IN}} = ?$$