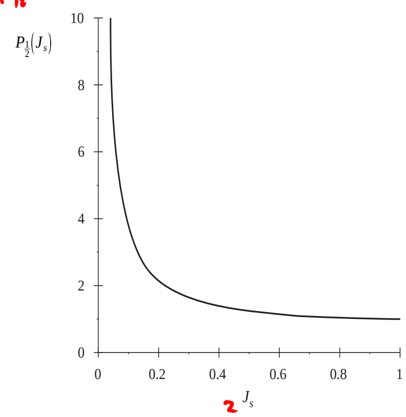
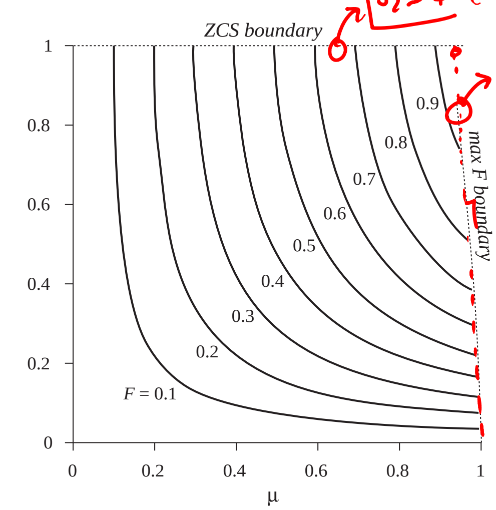
# Analysis result: switch conversion ratio μ

$\mu = F P_{1/2}(J_2)$




# Characteristics of the half-wave ZCS resonant switch




$J_2 \le 1$

Constraint:

$\frac{2\pi}{F} \ge \alpha + \beta + \delta$

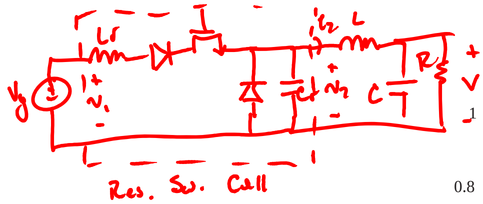
$\mu = \frac{F}{2\pi}\left[\frac{\alpha}{2} + \beta + \delta\right]$

$1 \ge \frac{F}{2\pi}\left[\alpha + \beta + \delta\right]$

$1 \ge \mu + \frac{F}{2\pi}\frac{J_2}{2}$

$\mu \le 1 - \frac{F J_2}{4\pi}$

## Buck converter containing half-wave ZCS quasi-resonant switch




in steady state

$V = \langle v_2 \rangle$

$\langle v_1 \rangle = V_g$

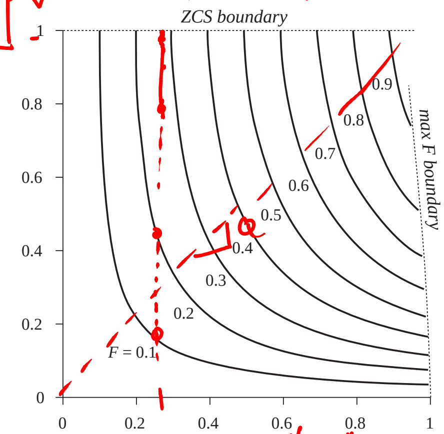
$J = J_2$

$M = M$

PWM : $M(d) = \frac{V}{V_g}$

Res : $M(\mu) = \frac{V}{V_g}$

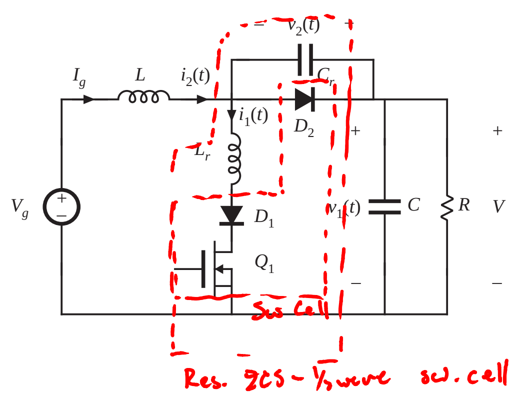
Output Plane




$M = \mu = \frac{V_2}{V_1} = \frac{I_1}{J_1}$

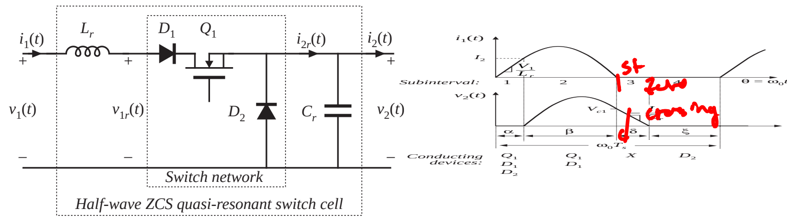
## Boost converter example

$M = \frac{1}{1-\mu}$

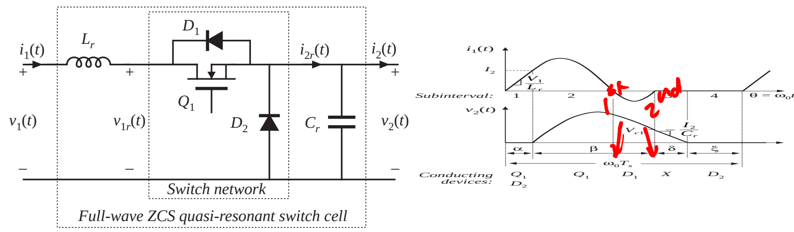


## 20.1.3 The full-wave ZCS quasi-resonant switch cell

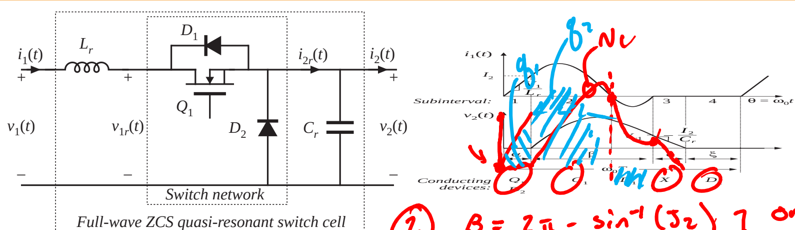
Half wave

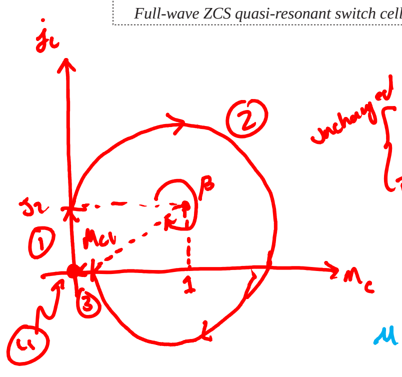



Full wave




# Analysis: full-wave ZCS



② $\beta = 2\pi - \sin^{-1}(J_2)$, $M_{c1} = 1 - \sqrt{1 - J_2^2}$ } only changes

unchanged [ ① → $\alpha = J_2$  ③ → $\delta = \frac{M_{c1}}{J_2}$

Bounds: $J_2 \le 1$  $\frac{2\pi}{F} < \alpha + \beta + \delta$

$\langle i_1 \rangle = \frac{1}{T_s}\left[q_1 + q_2\right]$

$\mu = F\frac{1}{2\pi}\left[\frac{J_2}{2} + 2\pi - \sin^{-1}(J_2) + \frac{1 - \sqrt{1 - J_2^2}}{J_2}\right]$

# Full-wave cell: switch conversion ratio μ

Looks like $\mu \approx F$

if $M_{c1} \approx 0$ & $\alpha \ll \frac{2\pi}{F}$ $(\varphi_1 \ll \varphi_2)$

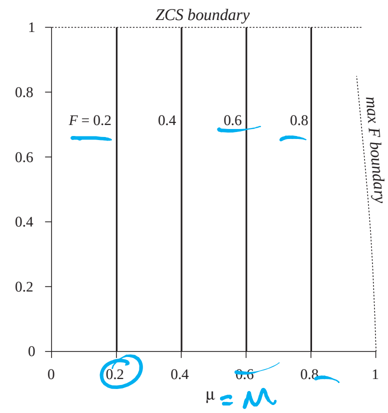
$\langle i_1 \rangle \approx \frac{1}{T_s}[I_2 t_2]$

$\mu = \frac{\langle i_1 \rangle}{I_2} \approx \frac{1}{T_s} t_2$

if $t_2$ is exactly one full period of resonance $\delta = J_2$

$t_2 = \frac{1}{f_0}$

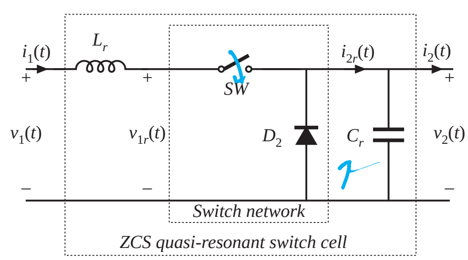
$\mu \approx \frac{f_s}{f_0} = F$




# 20.2 Resonant switch topologies

Basic ZCS switch cell:

ZCS – QR




SPST switch *SW*:

- Voltage-bidirectional two-quadrant switch for half-wave cell
- Current-bidirectional two-quadrant switch for full-wave cell

Connection of resonant elements:

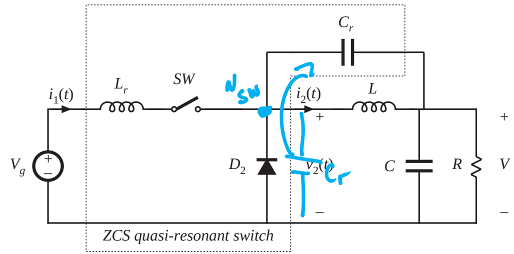
Can be connected in other ways that preserve high-frequency components of tank waveforms

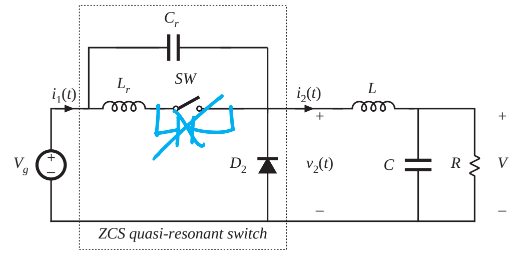
# Connection of tank capacitor

Connection of tank capacitor to two other points at ac ground.

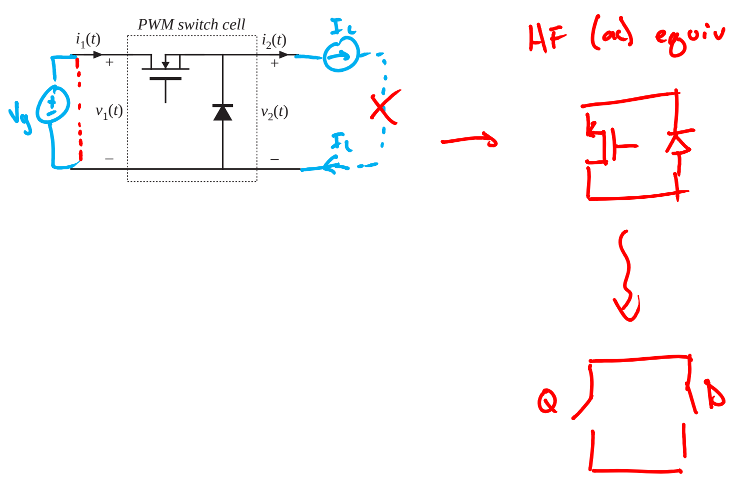
This simply changes the dc component of tank capacitor voltage.

The ac high-frequency components of the tank waveforms are unchanged.

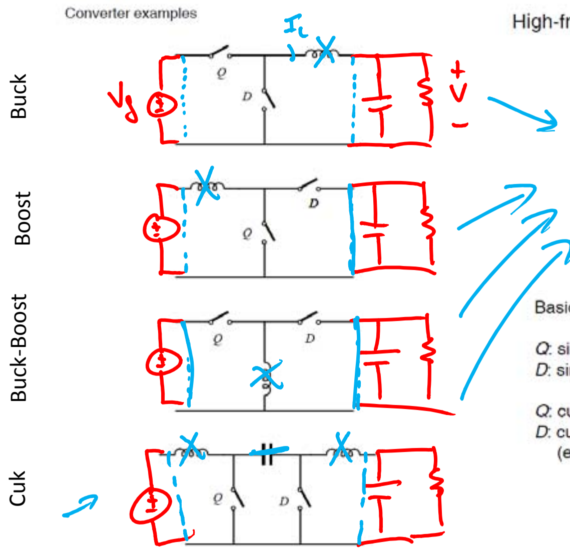


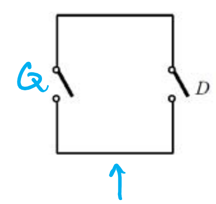

# PWM switch cell topology: HF (ac) view



# PWM Switch Cell of PWM Converters




High-frequency view of the switch network




Basic switch implementation options

*Q*: single-quadrant (transistor)
*D*: single-quadrant (diode)

*Q*: current-bidirectional (e.g. MOSFET)
*D*: current-bidirectional synchronous rectifier (e.g. MOSFET)

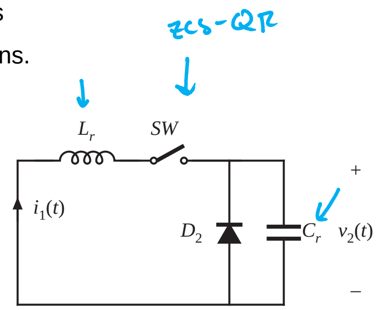
## A test to determine the topology of a resonant switch network

Replace converter elements by their high-frequency equivalents:

- Independent voltage source $V_g$: short circuit
- Filter capacitors: short circuits
- Filter inductors: open circuits

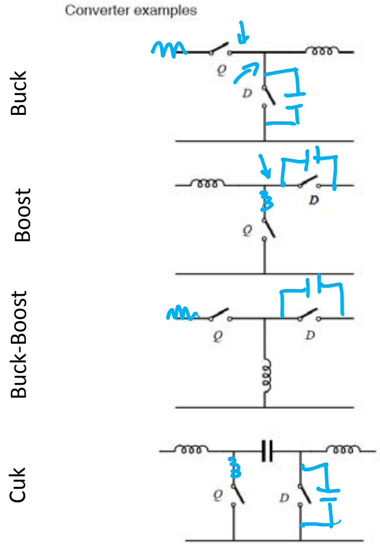
The resonant switch network remains.

If the converter contains a ZCS quasi-resonant switch, then the result of these operations is

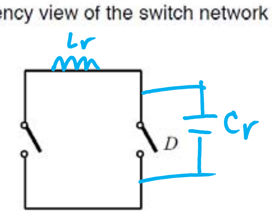


# ZCS-QR

Converter examples




High-frequency view of the switch network




Basic switch implementation options

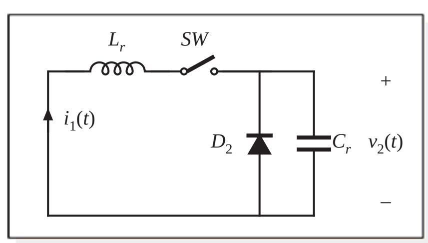
*Q*: single-quadrant (transistor)
*D*: single-quadrant (diode)

*Q*: current-bidirectional (e.g. MOSFET)
*D*: current-bidirectional synchronous rectifier (e.g. MOSFET)

# Zero-current and zero-voltage switching

ZCS quasi-resonant switch:

- Tank inductor is in series with switch; hence *SW* switches at zero current
- Tank capacitor is in parallel with diode $D_2$; hence $D_2$ switches at zero voltage




Discussion

- Zero voltage switching of $D_2$ eliminates switching loss arising from $D_2$ stored charge.
- Zero current switching of SW: device $Q_1$ and $D_1$ output capacitances lead to switching loss. In full-wave case, stored charge of diode $D_1$ leads to switching loss.
- Peak transistor current is $(1 + J_s)\, V_g/R_0$, or more than twice the PWM value.