Integrated, Self-learning DC-DC Converter for Portable Applications

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Motivation

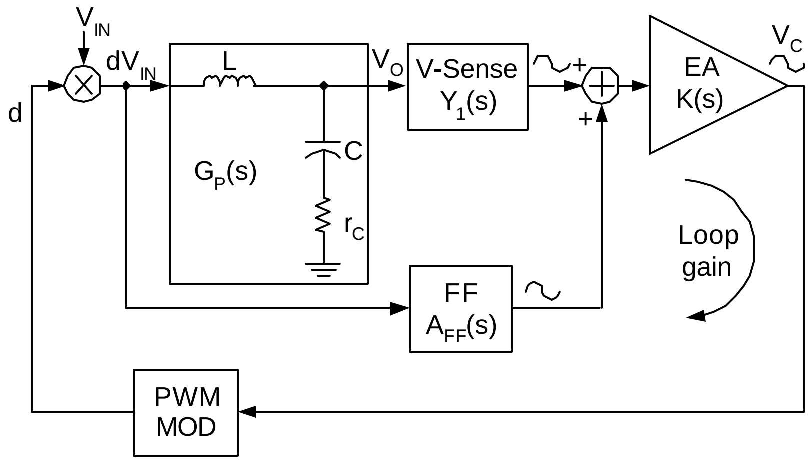
- Significant dependence of converter frequency response on passive components
- Tolerances in capacitor ESR, ESL values
- Variations in inductor, capacitor values per design

- IC solution for frequency compensation required because
  - Reduction in design time
  - Reduction in part count
  - Reduction in board size, cost
  - Ease of design

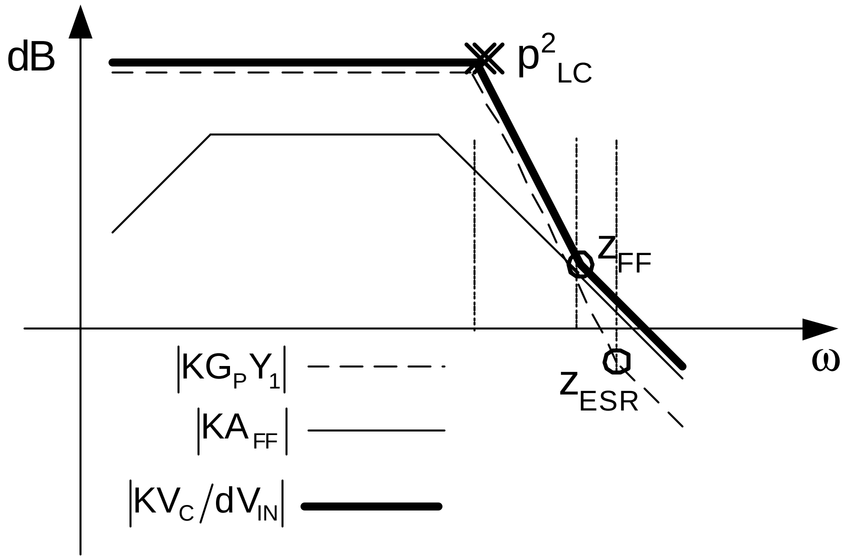
- *Need to have IC solution that will give frequency compensation independent of external components*

➢ Various techniques in literature are investigated next

Method 1: Masking Unreliable Capacitor ESR zero



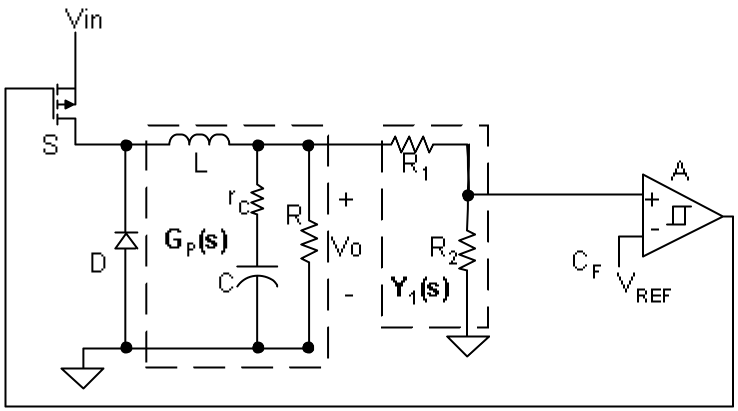
Block schematic with feedforward path



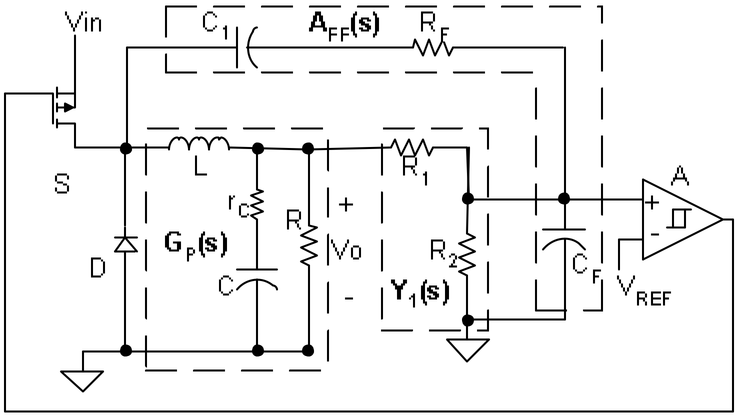
Loop gain including feedforward path

- ***Introduce artificial, reliable feedforward zero***
  - ✓ Feedforward path introduces reliable zero at frequency z_{FF}
  - ✓ Zero at z_{FF} dominates ESR zero in loop gain
  - • Similar application in hysteretic control

Method 1a: Modified Hysteretic Control



Voltage hysteretic control



Modified voltage hysteretic control

✓ Inherently stable
✓ Fast response
✓ Simple control

× Cap ESR r_C affects performance and stability

- Feedforward path R_F-C_F

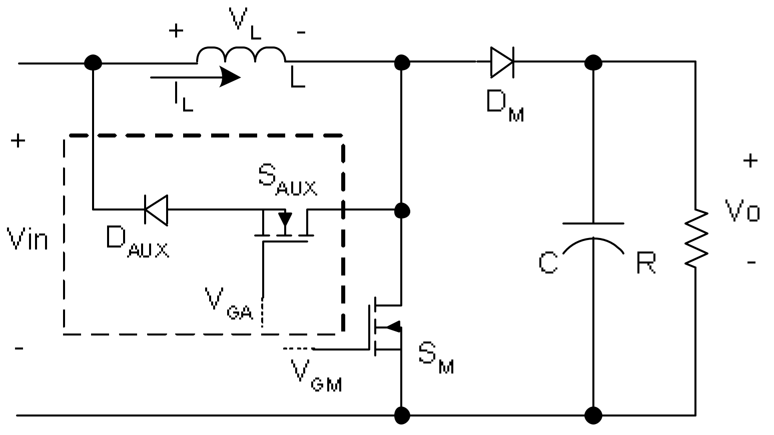
✓ LCR filter *masked*
✓ Other benefits of hysteretic converter maintained

× Applicable only to buck converter

Method 2: Elimination of RHP Zero in Boost/Buck-boost converter

- ***Constant capacitor discharge time***

- Auxiliary switch diode freewheels inductor current
- Total capacitor discharge time 0-t2
- Freewheeling time controlled to keep t2 constant



Gains

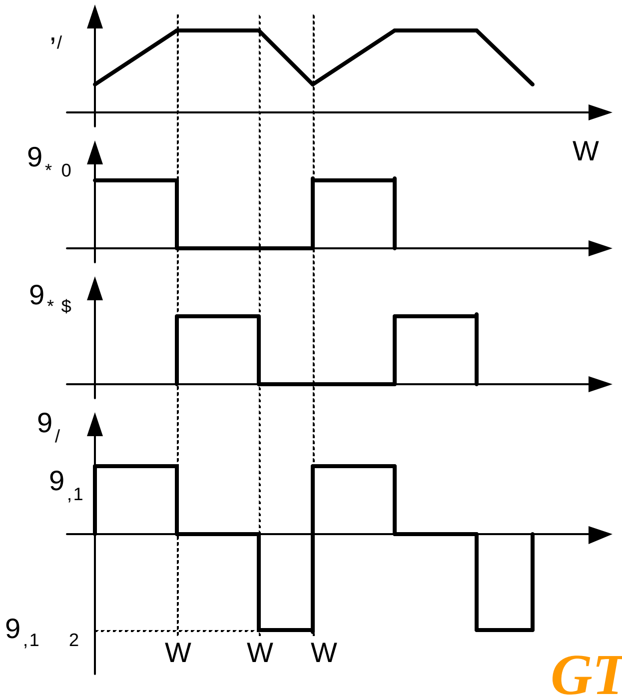
✓ RHP zero eliminated, simple control

✓ Filter poles independent of Q-point

Drawbacks

× Inductor current ?, I^2R power losses ?

× Four switches, same f_{sw}-Switch losses ?



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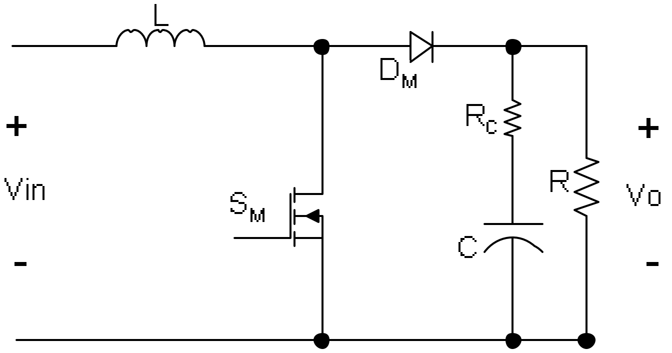
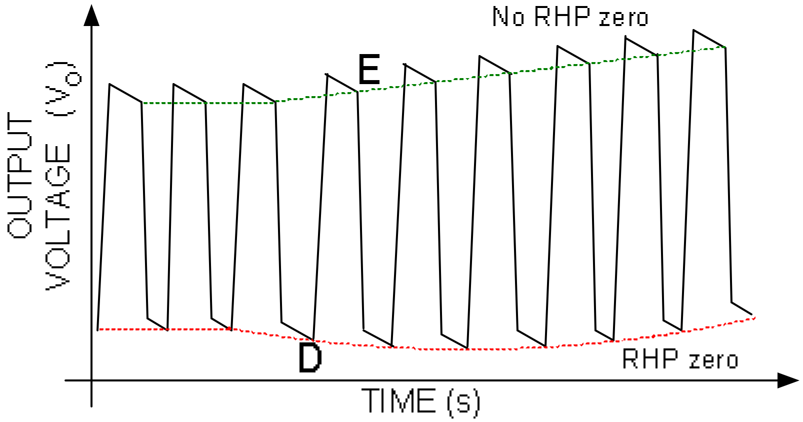
Method 3: Masking RHP Zero in Boost/Buck-boost converter





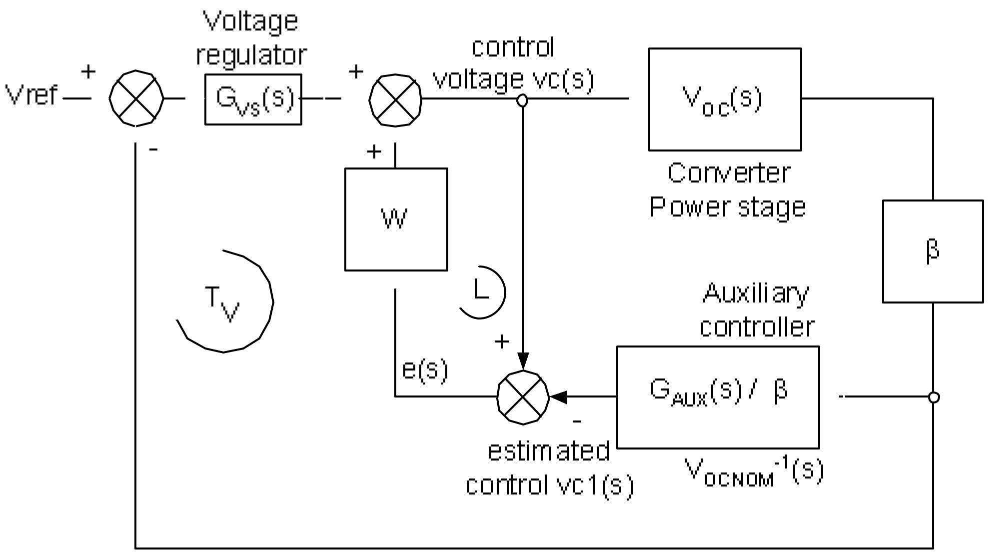
- ***Masking RHP zero using capacitor ESR***
  - Feed back output voltage *peak* with no “voltage dip” – no RHP zero
  - ESR large enough to overcome capacitor voltage drop

✓ RHP zero *masked out* from loop gain

✕ Large ESR required – voltage ripple worsened

✕ High frequency feedback loop – noise issues

Method 4: Compensating for LCR Filter Variations



▪ ***Constant LCR load control***

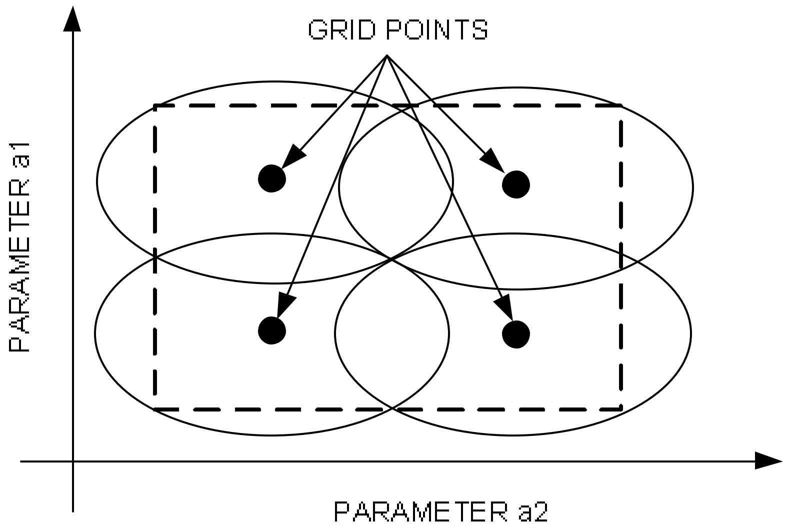
• Auxiliary controller & LC filter present constant LCR impedance

✓ Effective impedance seen by compensator is independent of LCR

× Positive feedback loop L can introduce additional instability

× Inapplicable to boost/buck-boost converters

Method 5: Grid Point Control



▪ ***Multiple operating point control***

- Multiple possible quiescent points based on various LCR values
- Suitable stable operating point chosen per actual LCR values

✓ Stable operation obtained over a wide range of LCR values

✕ Tedious technique to implement

✕ Instability possible during changeover between two points

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Comparison of Stabilizing Techniques

	Masking LCR (and/or ESR) Parameters			RHP Zero Elimination		Adaptive control		Boundary control
Characteristic	Feedforward	Modified Hysteretic	Constant LCR load	Constant capacitor discharge	Output peak control	Multiple operating point	Digital control	Voltage hysteretic control
Complexity	Medium	Low	Highest	Medium	Medium	High	High	**Lowest**
Response	Slowest	Fast	Medium	Medium	Slow	Slow	Slow	**Fastest**
Noise tolerance	**High**	Low	**High**	**High**	Low	**High**	**High**	Low
Power losses	**Low**	Medium	**Low**	Highest	**Low**	**Low**	**Low**	**Low**
Output ripple	Low	**Lowest**	Low	Low	High	Low	Low	Low
Stable – LCR variation	Medium	**Highest**	High	Low	Lowest	High	High	High
Versatility	**Highest**	Low	Low	Low	Low	High	High	Medium

Conclusion

➢Hysteretic control based scheme to be extended to boost converter

Future Work

Self learning controller design ideas

- Extension of hysteretic control based schemes in boost converter – *expected benefits*
  - Simpler control
  - Fast transient response
  - Independence of stability from LCR parameters

Controller design challenges

- Design complexity and ease of use
- System size and cost
- Application under wide operating conditions
- Methodology to be possibly scalable to different converter types