Design and Evaluation of an Active Ripple Filter Using Voltage Injection

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Abstract

Active ripple filters can substantially attenuate power converter ripple, allowing considerable reduction in passive filter component size. This paper explores an active filter topology that achieves voltage ripple reduction by injecting a compensating voltage across a series filter element. Both feedforward and feedback ripple cancellation are employed for maximum performance. Design of the sensor, amplifier and injection circuitry are explored, as is the use of active damping. Performance of the technique is demonstrated experimentally on a 250 watt dc/dc converter. The proposed technology is most effective where it is desirable to minimize the amount of filter capacitance.

Hybrid Passive/Active Filter

Passive Circuit

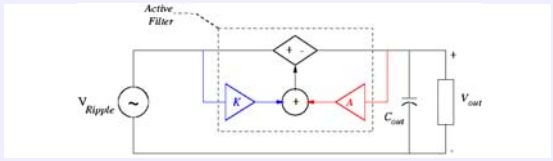
- Passive components (not shown) limit ripple source to a level manageable by active circuitry.
- Small passive components are used to attenuate ripple components that fall beyond the bandwidth of the active circuitry.

Active Circuit

- Injects a cancellation signal in series with ripple source
- Feedforward control: Perfect unity gain results in zero output ripple

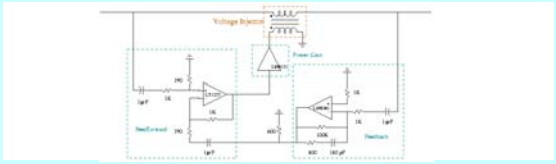
  The precision of the feedforward control is limited by the non-idealities of the amplifier and injector
- Feedback control: Infinite gain results in zero output ripple,

  The feedback gain is limited by the system dynamics and loop stability
- Key Elements: Injector, sensor, control, and active damping

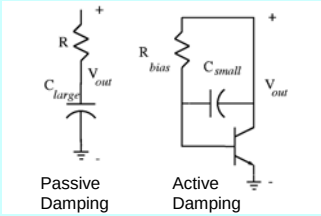


Sensor, Control, and Damping

- Precision and stability are the main design challenges



- Damping can be active or passive
- Active damping minimizes capacitance



The current that flows through the small capacitor is amplified by the transistor. The resistor biases the transistor into the linear region. A factor of 1000 reduction in damping capacitance is achievable with this method.

Voltage Ripple Injector

Challenges

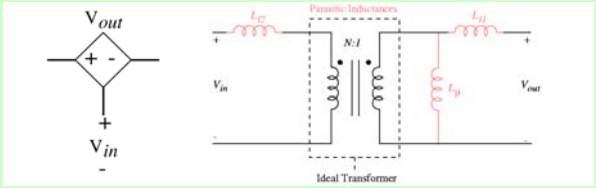
- Injector is in the main power path so it must carry the full DC current.
- Injector must have high input impedance and isolate the active circuitry.
- Voltage injector needs to replicate amplifier signal with high fidelity.

Transformer Circuit Solution

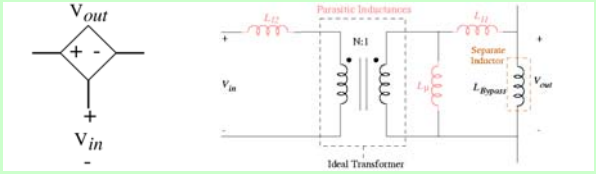
- The magnetizing inductance of transformers have minimal DC losses.
- The magnetizing inductance and the transformer turns ratio provide the active circuitry with a substantial input impedance.
- By minimizing the parasitic inductances and other non-idealities the transformer can achieve high signal fidelity.

Voltage Injector Implementations

Approach 1: Single magnetic element: gapped transformer



Approach 2: Two magnetic element: un-gapped transformer and DC bypass inductor in parallel

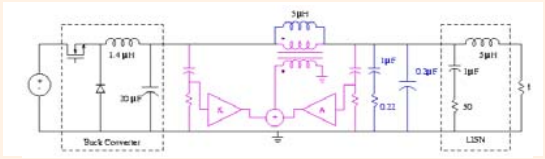


Comparison:

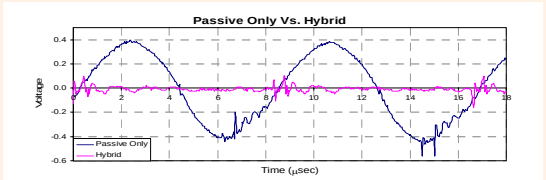
- The single magnetic component has less magnitude error.
- The two magnetic component implementation yields a 50% reduction in total volume, but requires gain compensation.

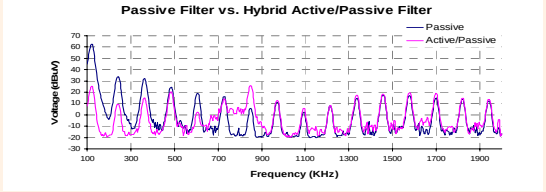
Experimental Results

- Output filter for 250 watt, 125 kHz Buck converter.

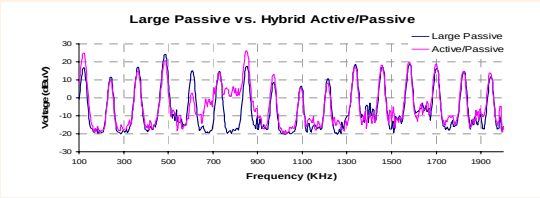


- Active injection dramatically reduces voltage ripple





- Active filter provides almost a 35 dB attenuation of the fundamental
- The largest ripple component across frequency is about 25 dB μVolts.
- Performance equivalent to much larger filter capacitor.



- The active filter allows a 20 μF capacitor to be replaced by a 0.2 μF capacitor, which is a factor of 100 improvement.

Conclusion

Active voltage injection used in conjunction with active damping effectively minimizes the needed capacitance in a filter. Experimental results have demonstrated capacitance reduction by a factor of 100 without impacting ripple performance.

Acknowledgments

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