Common-Mode Conducted EMI Reduction Using Inverse Waveform Cancellation
Randall B. Elliott P.E.
Randoid LLC

Problem

Passing Class B Conducted EMI can be an arduous task that is often mitigated by using brute-force filtering, transformer shielding and other “conventional wisdom” approaches that add cost, size and parts. However, options are limited if no AC ground (2-wire input) is used, if 50-60Hz leakage current to the output is problematic, if space is a problem, and/or if a cheaper solution is desired. This inexpensive EMI reduction method attacks the lowest frequency common-mode EMI at one of the notorious sources. The method described here is shown effective in a single positive output flyback power supply although other implementations may be possible.

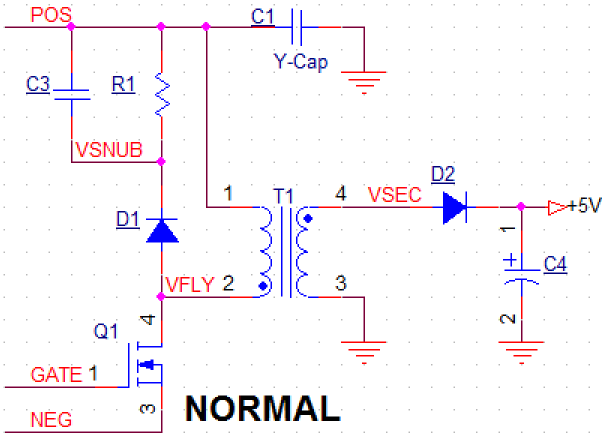
Source

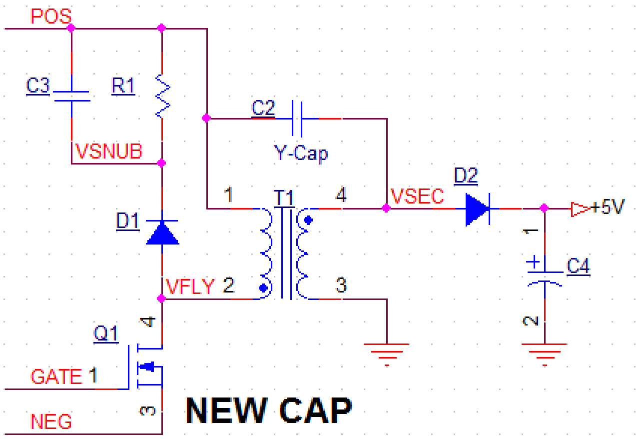
One source of common-mode leakage current is formed by the primary switching voltage waveform presented at the primary winding through the interwinding capacitance to the secondary winding. This primary leakage current can be simply described using **i = C dv/dt** where **dv/dt** is the voltage waveform and **C** is the interwinding capacitance. The total interwinding capacitance can be measured but the functional interwinding capacitance is substantially less since only one end of both the primary and secondary are active as well as other possible factors like winding overlap and such. Regardless, using about 1/4 of the transformer’s measured interwinding capacitance is a close enough estimate.

This common-mode current takes an inordinately large value common-mode choke to reduce it especially since the primary waveform is such a low frequency. While the Class-B limit conveniently ramps up 10db below 500KHz, this may still be the troubling area on some power supplies.

First Cure

This approach uses the secondary-side switching voltage connected through a “new” Y-cap to generate a current equal and opposite to the primary leakage current described above. This inverted current is simply described again using **i = C dv/dt** where **C** is the “new” Y-cap value, the **dt** is about the same as on the primary-side, and the secondary-side **dv** is conveniently the primary-side **dv divided by the transformer Turns Ratio**.





In its simplest implementation on a typical single positive output flyback supply (see above), simply remove the existing “normal” Y-cap and add a “new” Y-cap connecting a primary common to the other end of the secondary winding which is traditionally connected to the output diode anode (see above). This forces the inverted secondary voltage through the “new” Y-cap applying it in series with the leakage capacitance causing the opposing currents to cancel.

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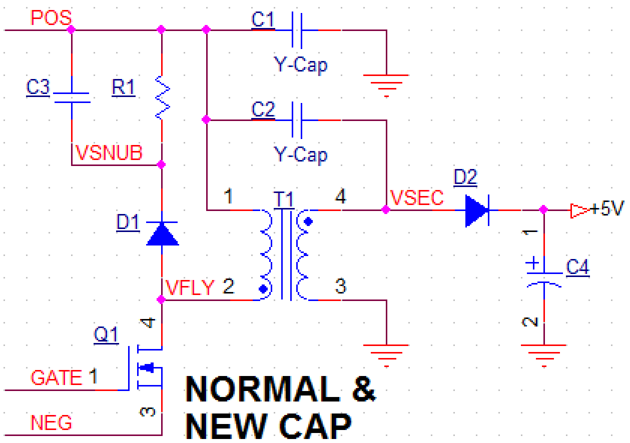
This implies that the “new” Y-cap value will likely be around 100pF to make the currents cancel. This may be only 5-10% of the prior “normal” Y-cap. Estimating the “new” Y-cap value is simply the primary-secondary **leakage capacitance divided by 4** and **multiplied by the Turns Ratio** as explained above. There may be further factors added by various transformer construction methods. Being this approach uses transformer turns-ratio, it is unaffected by the applied AC voltage level. In my actual implementation, leakage capacitance measured 20pF and turns ratio is 14:1 making the estimated value 70pF. After experimentation, the optimum value was found to be around 68pF to 100pF.

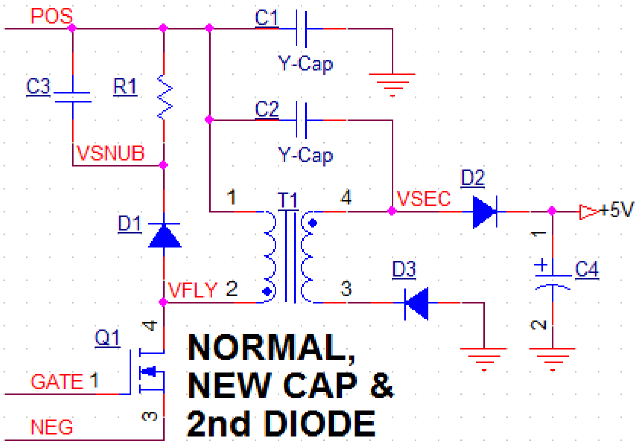
First Limitations, Complications and Mitigations

Transformer leakage inductance and other contributors will distort the **dt** waveform on the secondary side making complete cancellation impossible specifically at higher frequencies. Therefore, an additional small “normal” Y-cap may be needed to deal with this noise (see below). In my actual implementation, 100pF was conveniently quite sufficient.

Second Cure

The primary leakage current can be further isolated by adding a second diode in the ground leg (see below). This arrangement will cause the secondary winding to be disconnected from the rest of the secondary output circuitry when the diodes stop conducting at the end of the flyback portion of the switching cycle. This keeps resonances and other noise sources that occur in between conduction cycles more isolated on the primary side. This is particularly effective at frequencies over about 5MHz.



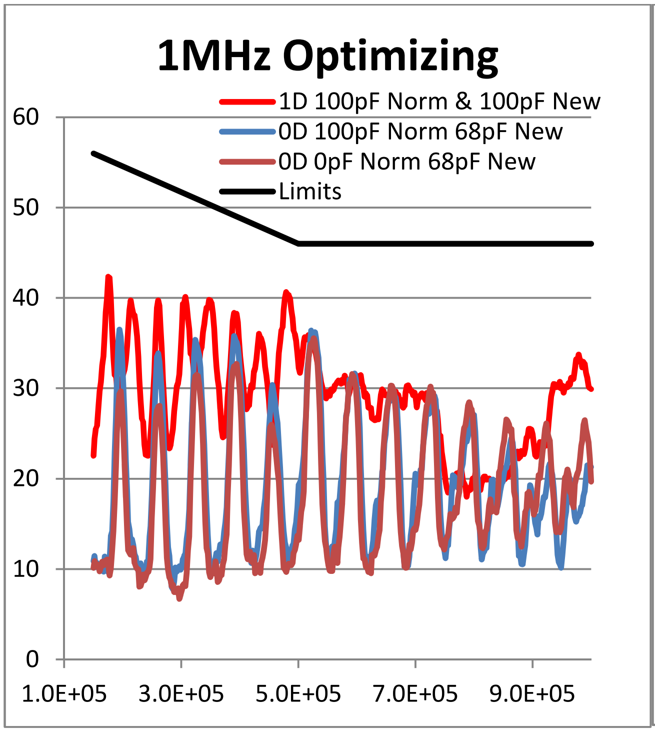


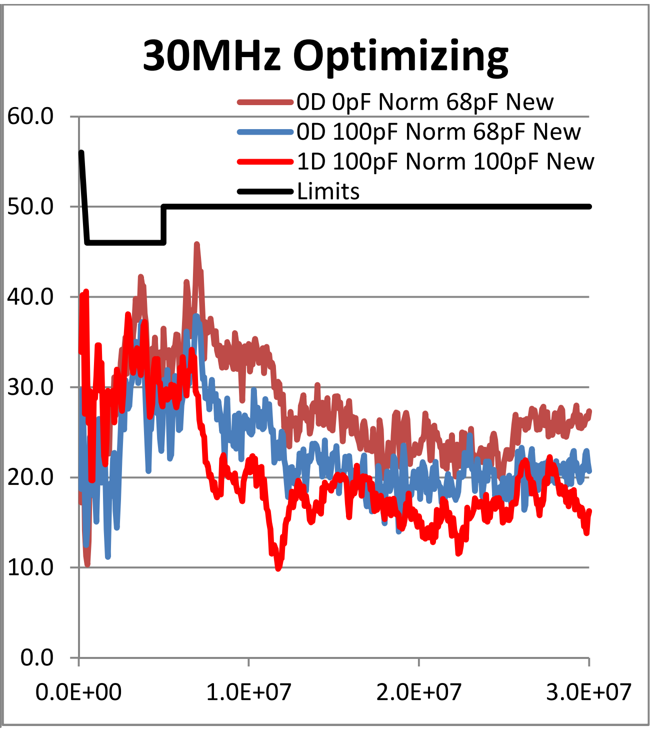
Second Limitations, Complications and Mitigations

Adding a “normal” Y-cap or secondary diode does increase cost and power dissipation. As per typical engineering, cost increase and performance reduction will have to be weighed against the benefits of the modification.

Fine Tuning

Improvements by adding the diode or a “normal” cap may be overkill if there is no compliance threat in the frequency ranges affected by those two changes. As the Spectrum Analysis shows (see below), adding a diode (1D versus 0D) may cost a bit of margin below 500KHz.





Also of note, the 100pF “normal” capacitor may be omitted if there is enough margin. Adding or omitting the diode or “normal” Y-cap may change the “new” capacitor value a bit. In my actual implementation, the optimum value changed between 68pF and 100pF. Either way, the optimum value should be established by experimentation. If the transformer construction changes afterwards, the optimum value should be verified and possibly reestablished.

Final Notes

Using only 2 diodes without any Y-caps appears quite ineffective at noise reduction.

My LTspice model’s FFT calculates similar noise reductions as the experiments demonstrate. There is a 20db EMI reduction below 3MHz from using a 680pF “normal” Y-cap to using a using a 68pF “new” Y-cap and a 100pF “normal” Y-cap. The LTspice models, waveform captures and spectrum analysis are available on request from **randoid@ieee.org**.