EMI Filter Design Example

This is a very small 1 hour session based on our 2 Day EMI Filter Design Workshop

Dr Ali Shirsavar
Biricha Digital Power Ltd
PSU Specification

- Input voltage \( \rightarrow \) \( V_i = 12V \)
- Output power \( \rightarrow \) \( P_o = 6.75W \)
- Efficiency \( \rightarrow \) \( \eta = 85\% \)
- PSU closed loop input impedance \( \rightarrow \) \( Z_{in} = 18\Omega \)
- Desired single stage filter output impedance \( \rightarrow \) \( Z_{o} = Z_{in}/10 < 2\Omega \)
- Input current \( \rightarrow \) \( I_{in} = V_i/Z_{in} = 660mA \)
- Switching frequency \( \rightarrow \) \( F_s = 200kHz \)
- Lowest frequency of interest \( \rightarrow \) \( F_h = 200kHz \)
- Harmonic number of \( F_h \) \( \rightarrow \) \( n = 1 \)
- PSU Loop cross over frequency \( \rightarrow \) \( F_x = 2kHz \)
- Reflected Ripple Current** @ \( F_h \) (no filtering, simulated) \( \rightarrow \) \( I_{rr, RMS} = 760mA \)
- Estimated Duty / \( \eta \) \( \rightarrow \) \( = 42\% \)
- Reflected Ripple Current @ \( F_h \) (no filtering, calculated) \( \rightarrow \) \( I_{rr, RMS} = \)
- Source Inductance \( \rightarrow \) \( L_{source} = 100uH \) (standard LISN)

Filter Specification

- Desired \( I_{rr} \) after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)

Filter Specification

- Desired Irr after filtering \( \rightarrow \) \( I_{rr, filtered, RMS} = 100dBuV \) (i.e. 2mA)
- Gain of single stage filter @ \( F_h \) \( \rightarrow \) \( Gain_{2nd, order} = 0.05 \)
- Single stage filter cut-off of frequency \( \rightarrow \) \( F_{c/o} = 10.3kHz \)
- Desired cut-off frequency of common mode filter \( \rightarrow \) \( F_{c/o, CM} = 75kHz \)
• Single Cell/Stage LC EMI Specification
  - Min Capacitance → $C_{1_{\text{min}}} = 8\mu\text{F}$
  - Max Capacitance → $C_{1_{\text{max}}} = 20\mu\text{F}$
  - Min Inductance → $L_{1_{\text{min}}} = 10\mu\text{H}$
  - Max Inductance → $L_{1_{\text{max}}} = 30\mu\text{H}$
  - Selected $C_1$ & Part No = $1 \times 10\mu\text{F} + (3 \times 4.7\mu\text{F on-board})$
  - Total $C_1$ after DC Bias Loss = $7.1\mu\text{F} + 12.3\mu\text{F} = \sim 20\mu\text{F}$
  - Combined ESR of $C_1$ @ Fs = $\sim 1\text{m}\Omega$
  - Frequency of ESR Zero due to $C_1$ → $F_{ESR0} = 8\text{MHz}$
  - Selected $L_1$ & Part No = $\sim 10\mu\text{H}$
  - Actual $F_{c/o} = 10\text{kHz}$
  - Actual Zo (not including $L_{\text{source}}$) = 0.7
  - Actual Zo (including $L_{\text{source}}$) = 2.3
  - Calculated Damping Cap → $C_d = \ldots$
  - Calculated Damping Resistor → $R_d = \ldots$
  - Actual Damping Cap → $C_d = 100\mu\text{F}$
  - Actual Damping R → $R_d = 0.42$
  - $Q$ (not including $L_{\text{source}}$) = 1.7
  - $Q$ (including $L_{\text{source}}$) = 5.6
EMI Filter Design Workshop

Day 1: Introduction to EMI Filter Design
- Filter design from ground up including LC & Pi filters with and without damping
- Power supply stability, Middlebrook’s stability criteria and input filter interaction
- Becoming comfortable with using spectrum analysers, LISNs and network analysers
- Using Biricha’s DC-DC EMI filter design software to speed up the design process
- Hands-on Labs, including:
  - LISN and Spectrum Analyser set-up for pre-compliance and EMC testing
  - Filter measurement with Bode100 network analyser
  - Step-by-step input and out filter design, implementation and testing

Day 2: AC/DC Line Filter Design
- Single Phase CCM Boost PFC topology operation & filtering needs
- Correct component selection, common mode chokes, differential mode choke, capacitors
- Designing high order/2-stage EMI filters
- AC-DC Line filter design & Biricha’s step-by-step Line filter design guide
- Hands-on Labs, including:
  - AC/DC Line filter design and measurement for PFCs
  - High order, 2 stage filter design and measurement
  - Correct filter component selection and routing

Aschheim (Near Munich)
June 19th to 20th 2018

For full details, syllabus and registration, please visit

www.biricha.com/emc
DC/DC Single Stage CM & DM EMI Filter Design Example

- **Cpi Design Calculations**
  - Rule 1: \( \text{Cpi} < \frac{C_1}{5} \)
  - Max Cpi due to \( C_1 = 20\mu\text{F} / 5 = 4\mu\text{F} \)
  - Rule 2: \( F_{\text{pi}} \) should be \( \pm 1 \) octave away from \( Fs \)
  - Actual \( L_1 = 10\mu\text{H} \)
  - Source Impedance \( L_{\text{source}} = 100\mu\text{H} \)
  - \( Fs \) to avoid resonance = 200kHz
  - So Cpi should be bigger than = 280nF
  - Or Cpi should be smaller than = 17nF
  - Rule 3: \( Z_{\text{Cpi}} \) @ \( Fs < 5\Omega \)
  - Cpi >= 160nF
  - Min Cpi Capacitance= 280nF
  - Max Cpi Capacitance= 4\mu\text{F}
  - Actual Cpi Selected = 1\mu\text{F}
  - \( F_{\text{pi}} = 52.8\text{kHz} \)

- **CM Choke Calculations**
  - Calculated CM Choke Inductance \( L_{\text{CM1}} = 0.5\text{mH} \)
  - Selected \( L_{\text{CM1}} \) & Part Number =
  - Calculated CM filter capacitance \( 2 \times \frac{1}{2} C_{\text{CM1}} = 9\text{nF} \)
  - Selected \( \frac{1}{2} C_{\text{CM1}} \) & Part No= 2 x 4.7nF