

ISL73847SEH 2-Phase Design Example with Calculations

The purpose of this document is to provide an example of how to calculate supporting components for the ISL73847SEH 2-phase applications. This document also introduces an Excel design calculator that automatically calculates all these values.

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1. 2-Phase Design

1.1 Initial Design Values

List out all the initial design values and any ISL73847SEH required parameters.

- $V_{IN} = 12V$
- $V_{OUT} = 1V$
- $V_{REF} = 0.6V$
- $I_{OUT(MAX)} = 50A$
- $n = 2$ (number of phases)
- $f_{SW} = 500kHz$
- $A_{CSA} = 8mV/mV$
- $I_{STEP} = 25A$
- $tran_{percent} = 2\%$
- $g_{m(EA)} = 4mA/V$
- $DRP_{percent} = 4\%$
- $I_{DROOP} = 19.9\mu A$
- $t_{SS} = 1ms$
- $I_{SS} = 10\mu A$

1.2 Determining the Frequency Select Resistor

The default internal switching frequency of the ISL73847SEH is 500kHz. To change the switching frequency, use a pull-down resistor from the FS pin to GND. Refer to the EC table in the datasheet for the recommended R_{FS} resistor values for 250kHz, 500kHz, 1MHz, and 1.5MHz switching frequencies, as these have been verified extensively. Use Equation 1 for other frequencies to calculate R_{FS} with less than 10% error, where f_{OSC} is twice the switching frequency (f_{SW}).

$$(EQ. 1) \quad R_{FS}[k\Omega] = \left(\frac{56497}{f_{SW}[kHz]} \right) - 20.96$$

$$R_{FS} = \left(\frac{56497}{1,000} \right) - 20.96$$

$$\therefore R_{FS} = 92k\Omega \rightarrow 94.2k\Omega$$

The equation suggests using a 92k Ω R_{FS} resistor. However, the EC table shows that a 94.2k Ω resistor gives a 1MHz internal oscillator frequency (500kHz PWM output switching frequency).

1.3 Determining the Output Voltage Feedback Resistors

The required output voltage is 1V, the internal voltage reference is 0.6V typical, and as a starting point Renesas suggests making R_1 4.99k Ω .

$$(EQ. 2) \quad V_{OUT} = V_{REF} \times \left(1 + \frac{R_2}{R_1} \right)$$

Rearrange the equation:

$$(EQ. 3) \quad R_2 = \left(\frac{V_{OUT}}{V_{REF}} - 1 \right) \times R_1$$

$$R_2 = \left(\frac{1}{0.6} - 1 \right) \times 4.99k\Omega$$

$$\therefore R_2 = 3.327k\Omega$$

A good option for R_2 is a 3.32k Ω resistor with $\pm 0.1\%$ tolerance. Calculating the output voltage with this value gives an output voltage of 0.999V.

1.4 Determining the Current-Sense Resistor

The target current-sense amplifier input voltage is 50mV, maximum output current is 50A, the number of phases is two, and the OCP1 sense voltage is 75mV.

$$(EQ. 4) \quad R_{SEN}[\Omega] = \frac{V_{SEN}[V] \times n}{I_{OUT(MAX)}[A]}$$

$$R_{SEN} = \frac{50 \times 10^{-3} \times 2}{50}$$

$$\therefore R_{SEN} = 2m\Omega$$

$$(EQ. 5) \quad P_{RSEN}[W] = \frac{V_{OCP1}[V]^2}{R_{SEN}[\Omega]}$$

$$P_{RSEN} = \frac{75 \times 10^{-3}^2}{2 \times 10^{-3}}$$

$$\therefore P_{RSEN} = 2.8W$$

1.5 Determining the Output Inductor

Use Equation 6 to calculate a good estimate for the output inductor based on a required ripple current, where $I_{OUT} = n \times I_{PHASE}$.

$$(EQ. 6) \quad L_{REC}[H] = \frac{(V_{IN} - V_{OUT})[V] \times D \times n}{k \times f_{SW}[Hz] \times I_{OUT(MAX)}[A]}$$

The input voltage is 12V, the calculated output voltage is 0.999V, the duty cycle is $D = 1V/12V = 0.0833$, the output switching frequency is 500kHz, the number of phases is 2, the required ripple current (k) is 30% and the max output current is 50A (2x25A).

$$\therefore L_{REC} = \frac{(12 - 0.999) \times 0.0833 \times 2}{500 \times 10^3 \times 50} = 244.5nH$$

A good option for the inductor between the calculated minimum and maximum inductor values is $L_{SEL} = 220nH$. This value is also close to the recommended value of 244nH, which targets a 30% total ripple current. Use Equation 7 to calculate the actual inductor ripple percentage for the chosen inductor.

$$(EQ. 7) \quad \text{ripple}[\%] = \frac{(V_{IN} - V_{OUT})[V] \times D \times n}{f_{SW}[Hz] \times I_{OUT(MAX)}[A] \times L_{SEL}[H]}$$

$$\therefore \text{ripple} = \frac{(12 - 0.999) \times 0.0833 \times 2}{(500 \times 10^3) \times 50 \times (220 \times 10^{-9})} = 33.3\%$$

1.6 Determining the Slope Compensation Resistor

Use Equation 8 to calculate the slope compensation resistor. R_{SEN} is 2m Ω , R_{FS} is 94.2k Ω , V_{OUT} is 0.999V, k is 25kV/s, L_{SEL} is 220nH. If the R_{SLOPE} calculated is less than 25k Ω , increase the L_{SEL} , and vice versa if R_{SLOPE} is greater than 100k Ω .

$$(EQ. 8) \quad R_{SLOPE}[\Omega] = \frac{R_{SEN}[\Omega] \times R_{FS}[\Omega] \times V_{OUT}[V]}{k \times L_{SEL}}$$

$$\therefore R_{SLOPE} = \frac{2 \times 10^{-3} \times 94.2 \times 10^3 \times 0.999}{25 \times 10^3 \times 220 \times 10^{-9}} = 34.23k\Omega$$

The equation suggests a 34.23k Ω R_{SLOPE} value, which is between 25k Ω and 100k Ω . A good option is 34.8k Ω .

1.7 Determining the Error-Amplifier Compensation Resistor

To calculate the output capacitor and compensation values, ΔV_{OUT} and ΔI_{OUT} must be known. ΔV_{OUT} is the amount of output voltage deviation during a load step, in this example it is $2\% \times 0.999V = 19.98mV$, and ΔI_{OUT} is the load step which is 25A. With these two known values, use [Equation 9](#) to calculate the equivalent load-line output impedance R_{LL} .

$$(EQ. 9) \quad R_{LL} = \frac{\Delta V_{OUT}}{\Delta I_{OUT}}$$

$$\therefore R_{LL} = \frac{19.98 \times 10^{-3}}{25} = 0.8m\Omega$$

With the load-line impedance, use [Equation 10](#) to calculate R_{COMP} , where V_{OUT} is 0.999V, R_{SEN} is 2m Ω , A_{CSA} is 8mV/mV, n is 2, V_{REF} is 0.6V, $g_{m(EA)}$ is 4mS, and R_{LL} is 0.8m Ω .

$$(EQ. 10) \quad R_{COMP} = \frac{V_{OUT}[V] \times R_{SEN}[\Omega] \times A_{CSA}[mV/mV]}{n \times V_{REF}[V] \times g_{m(EA)}[A/V] \times R_{LL}[\Omega]}$$

$$(EQ. 11) \quad R_{COMP} = \frac{0.999 \times 2 \times 10^{-3} \times 8}{2 \times 0.6 \times 4 \times 10^{-3} \times 0.8 \times 10^{-3}} = 4.17k\Omega$$

A good compensation resistor is a 4.22k Ω .

1.8 Determining the Output Capacitance

Use [Equation 12](#) to determine the minimum output capacitance. The compensation resistor is 4.22k Ω , the error amplifier transconductance is 4mA/V or 4mS, the internal voltage reference is 0.6V, f_T is the converter unity-gain frequency, which Renesas recommends setting a decade below the switching frequency ($f_T = f_{SW}/10 = 500kHz/10 = 50kHz$), A_{CSA} is 8mV/mV, and the calculated output voltage is 0.999V.

$$(EQ. 12) \quad C_{OUT(MIN)} = \frac{n \times R_{COMP}[\Omega] \times g_{m(EA)}[V/A] \times V_{REF}[V]}{2\pi \times f_T[Hz] \times A_{CSA}[mV/mV] \times R_{SEN}[\Omega] \times V_{OUT}[V]}$$

$$\therefore C_{OUT(MIN)} = \frac{2 \times 4.22 \times 10^3 \times 4 \times 10^{-3} \times 0.6}{2\pi \times 50 \times 10^3 \times 8 \times 2 \times 10^{-3} \times 0.999} = 4033\mu F$$

A good option is paralleling twenty-four 220 μF capacitors, or twelve per phase, which gives 5280 μF of bulk output capacitance. Optimizing this value is outside the scope of this paper; however, it is explained in the application note *Selecting Input and Output Capacitors for the ISL73847SEH*.

With the actual output capacitor value chosen, recalculate f_T by rearranging [Equation 12](#) to create [Equation 13](#).

$$(EQ. 13) \quad f_T[Hz] = \frac{n \times R_{COMP}[\Omega] \times g_{m(EA)}[V/A] \times V_{REF}[V]}{2\pi \times C_{OUT}[F] \times A_{CSA}[mV/mV] \times R_{SEN}[\Omega] \times V_{OUT}[V]}$$

$$\therefore f_T[Hz] = \frac{2 \times 4.22 \times 10^3 \times 4 \times 10^{-3} \times 0.6}{2\pi \times 5280 \times 10^{-6} \times 8 \times 2 \times 10^{-3} \times 0.999} = 38kHz$$

1.9 Determining the Error-Amplifier Compensation Capacitor

Use Equation 14 to determine the error-amplifier compensation capacitor. f_z is the zero frequency of the error amplifier. Renesas recommends setting the zero formed by R_{COMP} and C_{COMP} a decade smaller than the f_T ($f_z = f_T/10 = 38\text{kHz}/10 = 3.8\text{kHz}$), where R_{COMP} is $4.22\text{k}\Omega$.

$$\text{(EQ. 14)} \quad C_{COMP}[\text{F}] = \frac{1}{2\pi \times f_z[\text{Hz}] \times R_{COMP}[\Omega]}$$

$$\therefore C_{COMP} = \frac{1}{2\pi \times 3.8 \times 10^3 \times 4.22 \times 10^3} = 9.88\text{nF}$$

A good option for the compensation capacitor is 10nF .

1.10 Determining the Pole Capacitor

Adding a pole capacitor is recommended to cancel out the zero formed by the equivalent bulk output capacitance and ESR. To determine the pole capacitor, first determine the equivalent total ESR of the parallel combination of output capacitors. The $220\mu\text{F}$ output capacitors chosen have $6\text{m}\Omega$ of ESR individually, so the parallel combination of twenty-four of these output capacitors have an equivalent total ESR of $6\text{m}\Omega/24 = 0.250\text{m}\Omega$, as shown in Equation 15.

Note: This equation and the ones that follow apply only if all capacitors in parallel are identical with equal capacitance and ESR values.

$$\text{(EQ. 15)} \quad ESR_{TOTAL}[\Omega] = \frac{ESR[\Omega]}{\# \text{ of capacitors}}$$

$$\therefore ESR_{TOTAL} = \frac{6 \times 10^{-3}}{24} = 0.250\text{m}\Omega$$

Optimizing this value is outside the scope of this paper; however, it is explained in the application note *Selecting Input and Output Capacitors for the ISL73847SEH*.

Lastly, add a pole to the controller loop at the same frequency as the zero formed by the equivalent C_{OUT} and ESR, using Equation 16.

$$\text{(EQ. 16)} \quad C_{POLE}[\text{F}] = \frac{C_{OUT}[\text{F}] \times ESR[\Omega]}{R_{COMP}[\Omega]}$$

$$\therefore C_{POLE} = \frac{5280 \times 10^{-6} \times 0.25 \times 10^{-3}}{4.22 \times 10^3} = 313\text{pF}$$

A good option for the pole capacitor is 330pF .

1.11 Determining the Droop Regulation Resistor and Capacitor

Use Equation 17 to determine the droop resistor. The required percentage of droop regulation at full load is 4%, the internal voltage reference is 0.6V , the droop current is $19.9\mu\text{A}$, the number of phases for this design is 2, and one ISL73847SEH Controller.

$$\text{(EQ. 17)} \quad R_{DROOP}[\Omega] = \frac{DRP_{\text{percent}} \times V_{REF}[\text{V}]}{I_{DROOP}[\mu\text{A}] \times n} \times \# \text{ of Controllers}$$

$$\therefore R_{\text{DROOP}} = \frac{4\% \times 0.6}{(19.9 \times 10^{-6}) \times 2} \times 1 = 0.603\text{k}\Omega$$

A good option for R_{DROOP} is 0.604k Ω . Use Equation 18 to determine the droop capacitor. The compensation resistor is 4.22k Ω , and the compensation capacitor is 10nF.

$$\text{(EQ. 18)} \quad C_{\text{DROOP}}[\text{F}] = \frac{R_{\text{COMP}}[\Omega] \times C_{\text{COMP}}[\text{F}]}{R_{\text{DROOP}}[\Omega]}$$

$$\therefore C_{\text{DROOP}} = \frac{4.22 \times 10^3 \times 10 \times 10^{-9}}{0.604 \times 10^3} = 70\text{nF}$$

A good option for C_{DROOP} is 82nF.

1.12 Determining the Soft-Start Capacitor and In-Rush Current

Use Equation 19 to determine the soft-start capacitor. The required soft-start time is 1ms, the soft-start current is 10 μ A and the voltage reference is 0.6V.

$$\text{(EQ. 19)} \quad C_{\text{SS}}[\text{F}] = \frac{t_{\text{SS}}[\text{s}] \times I_{\text{SS}}[\text{A}]}{V_{\text{REF}}[\text{V}]}$$

$$\therefore C_{\text{SS}} = \frac{0.001 \times 10 \times 10^{-6}}{0.6} = 17\text{nF}$$

A good option for C_{SS} is 22nF.

Use Equation 19 to calculate the expected soft-start time with this C_{SS} value.

$$\text{(EQ. 20)} \quad t_{\text{SS}}[\text{s}] = \frac{0.022 \times 10^{-6} \times 0.6}{10 \times 10^{-6}}$$

$$\therefore t_{\text{SS}} = 0.0013\text{s}$$

Use Equation 21 to calculate the in-rush current. The output capacitance is 5280 μ F, the calculated output voltage is 0.999V, and the duty cycle is 0.0833.

$$\text{(EQ. 21)} \quad I_{\text{RUSH}}[\text{A}] = \frac{D \times V_{\text{OUT}}[\text{V}] \times C_{\text{OUT}}[\text{F}]}{t_{\text{SS}}[\text{s}]}$$

$$\therefore I_{\text{RUSH}}[\text{A}] = \frac{0.0833 \times 0.999 \times 5280 \times 10^{-6}}{0.0013} = 0.333\text{A}$$

1.13 Summary of all the Calculated Component Values

- $R_{FS} = 92k\Omega \approx 94.2k\Omega$ (value pulled from the EC table)
- $R_1 = 3.327k\Omega \approx 3.32k\Omega$, with $\pm 0.1\%$ tolerance
- $R_2 = 4.99k\Omega$
- $V_{OUT} = 0.999V$
- $R_{SEN} = 2m\Omega$
- $R_{FIL} = 30.1\Omega$
- $C_{FIL} = 680pF$
- $L_{OUT} = 220nH/phase$
- $R_{SLOPE} = 34.23k\Omega \approx 34.8k\Omega$
- $R_{COMP} = 4.17k\Omega \approx 4.22k\Omega$
- $C_{OUT} = 220\mu F \times 24 = 5280\mu F$ (2640 $\mu F/phase$)
- $C_{COMP} = 9.8nF \approx 10nF$
- $R_{DROOP} = 0.603k\Omega \approx 0.604k\Omega$
- $C_{DROOP} = 70nF \approx 82nF$
- $C_{SS} = 17nF \approx 22nF$
- $C_P = 330pF$

Figure 1 shows an image of the ISL73847x Design Tool (Excel file) that automatically calculates all of these values for the 2-phase application design.

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
ISL73847x Design Tool (Rev 4.0)														
Input Voltage (V _{in})	12	V		Use DROOP?	Yes									
Output Voltage (V _{out})	1	V		Target ΔV_{out} with DROOP (DRP _{percent})	4	%								
Max Load Current (I _{OUT(MAX)})	50	A		Output Load Step (ΔI_{out})	25	A								
Switching Frequency (f _{sw})	500	kHz		Target ΔV_{out} During Load Transient (tra _{percent})	2	%								
Oscillator Frequency (f _{OSC} = 2*f _{sw})	1,000	kHz		Recommended DROOP Resistance per Controller (R _{DROOP})	603	Ω								
Number of Phases (n)	2			Selected DROOP Resistor per Controller (R _{DROOP})	603	Ω								
Number of Controllers	1			DROOP Capacitor (C _{DROOP})	78.77	nF								
Duty Cycle (d)	8.333	%		Equivalent Load-Line Output Impedance (R _{LL})	0.799	m Ω								
Max ON Time (t _{on})	166.667	ns		Recommended Compensation Resistor (R _{COMP})	4.669	k Ω								
Max OFF Time (t _{off})	1833.333	ns		Selected Compensation Resistor (R _{COMP})	4.75	k Ω								
ON/OFF Time Problem?	No			Recommended Crossover Frequency (f _r =f _{sw} /10)	50.00	kHz								
Switching Frequency Problem? (250kHz ≤ f _{sw} ≤ 1,500kHz)	No			Minimum Output Capacitance (C _{OUT(MIN)})	4,051.55	μF								
Use External Clock on SYNC-1 (f _{OSC} 15%)?	No			Output Capacitance (C _{OUT})	5,280.00	μF								
Frequency Select Resistor (R _{FS})	94.2	k Ω		Crossover Frequency (f _r)	38.4	kHz								
Bottom Output Feedback Resistor (R _b)	4.99	k Ω		Bulk Capacitor ESR Equivalent (ESR _{OUT(MIN)})	0.25	m Ω								
Top Feedback Resistor (R _t)	3.327	k Ω		Bulk Output COUT/ESR Zero Frequency (f _z)	120.57	kHz								
Selected Top Feedback Resistor (R _t)	3.32	k Ω		Recommended Pole Capacitor (C _{POLE})	277.89	pF								
Calculated Output Voltage (V _{OUT})	0.999	V		Recommended Zero Frequency (f _r =f _r /10)	3.84	kHz								
Output f _{sw} on SYNC-0 pin?	100k Ω SYNC-0 to VCC			Recommended Compensation Capacitor (C _{COMP})	8.73	nF								
Output f _{SYNC-1} or f _{OSC} on SYNC-0 pin?	100k Ω SYNC-0 to GND			Selected Compensation Capacitor (C _{COMP})	10	nF								
Recommended Current Sense Resistor (R _{SEN})	2	m Ω		Zero Frequency (f _z)	3.35	kHz								
Selected Current Sense Resistor (R _{SEN})	2	m Ω		Target In-rush Current (I _{IRUSH})	0.333	A								
R _{SEN} Power Dissipation @ OCP1 (P _{RSEN})	2.813	W		Recommended Soft-Start Capacitor (C _{SS})	22.00	nF								
Target Ripple Current (ΔI)	30	%		Soft-Start Time (t _{SS})	1.32	ms								
Recommended Inductor Value (L _{REQ})	244.46	nH		Selected Soft-Start Capacitor (C _{SS})	22	nF								
Selected Inductor Value (L _{SEL})	220	nH		In-rush Current (I _{IRUSH})	0.333	A								
Inductor (L _{SEL}) Ripple Current (ΔI)	33.33	%		Soft-Start Time (t _{SS})	1.32	ms								
Inductor (L _{SEL}) Ripple Current per phase ($\Delta I_{(PHASE)}$)	8.333	A												
Slope Resistor (R _{SLOPE})	34.23	k Ω												
Slope Resistor Problem? (25k Ω ≤ R _{SLOPE} ≤ 100k Ω)	No													

Figure 1. Automatic Design Results for a 2-Phase ISL73847 Application Design

2. Conclusion

An Excel [ISL73847x Design Tool](#) that automatically calculates all the values derived in this document and more is available. However, it is beneficial to know how they were derived and to hand calculate some of the values.

3. Revision History

Revision	Date	Description
1.01	Dec 8, 2023	Updated $g_{m(EA)}$ value from 3.57 to 4 throughout. Updated Equations 11, 12, 13, 14, 16, and 18. Updated Summary of all the Calculated Component Values.
1.00	Nov 15, 2023	Initial release.

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