Current Sense Design Tool Tutorial

12/9/2025

Introduction

Welcome to the onsemi online current sense design tool where the normally iterative process of designing a current sense solution is made easier and straight forward. We will start by briefly showing the different pages of the tool and what content is displayed. We will then dive into the design process starting on the system parameters page where you will enter the know requirements and characteristics required by the current sense solution. Following system parameter entry, we will move the design worksheet to select a device and refine performance. A Design Summary sheet is included to wrap up the system characteristics and performance in a printable format for reference.

Before we get started showing a design example let's discuss what is really happening in a shunt based current sense application design. We normally have system accuracy requirements, power loss requirements and cost requirements that tend to be in opposition to each other. That is, lower loss selection for the shunt with higher gain selection will generally improve accuracy due to more precise metallurgy and trim in the shunt, but it will tend to drive a higher cost. So, this tool starts with a number of requirements dictated by the application, but you should be aware that one of the most important selections is the shunt power requirement. Allowing for the highest acceptable loses with the highest shunt resistance value that fit the system power loss budget, can help optimize system cost. Assigning lower loss may drive the recommended shunt value to a higher cost technology but will tend to enhance accuracy at the sense terminals. This tool can be used to run many scenarios to optimize the system component selection displaying current accuracy and resolution across load levels.

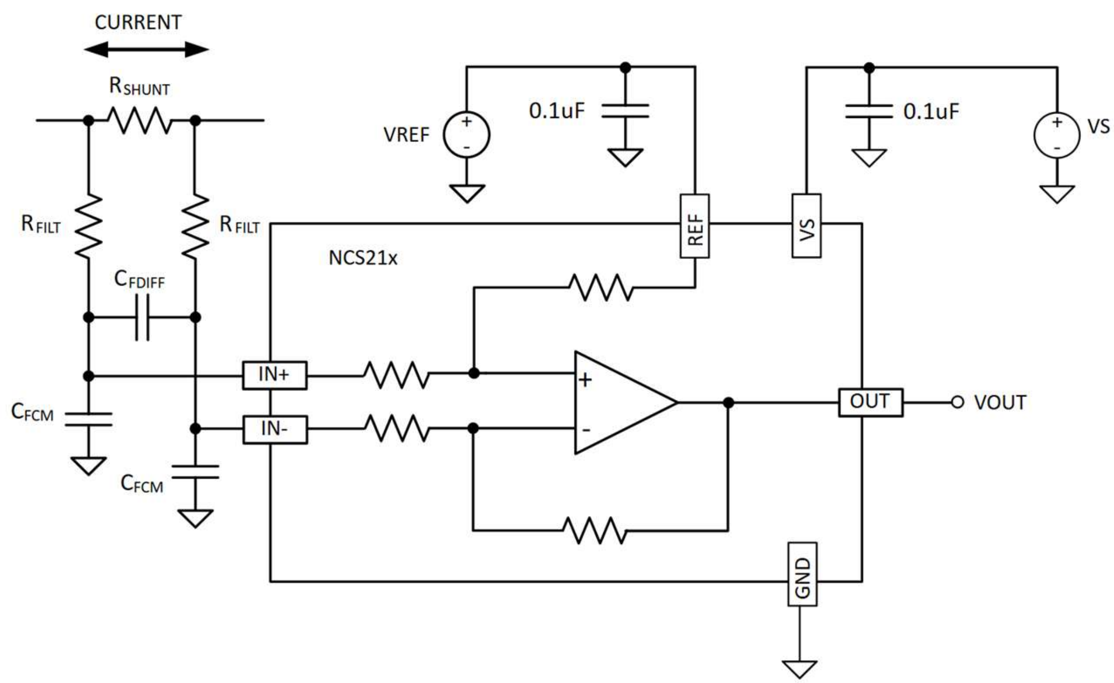
Tool structure

- So, what is the aim of this tool. Current sense circuit design is inherently iterative. Current sense amplifiers have many sources of error that need to be accounted for. Each has a pushing factor to the overall scaled current.
- Each of these datasheet characteristics including gain error, offset, temperature drift, common mode rejection etc. need to be evaluated for the specific operating conditions of the system.
- Additionally, external components such as input filter resistances and reference tolerances must also be considered to arrive at overall current sense error.
- A tool that calculates and incorporates these errors displaying the error vs current for numerous iterations can greatly speed up the design process and offer more iterations to aid in component selection. This tool works exclusively on the extreme value Min/Max specifications from the amplifier datasheet making it easy to expand to future devices

Symbol	Parameter		Test Conditions	Min	Typ	Max	Unit
INPUT							
V_{CM}	Common–Mode Input Voltage Range			**–0.3**		**26**	V
CMRR	Common–Mode Rejection Ratio (Note 7)	NCx210R, NCx211R, NCx214R	V_{IN+} = 0 V to +26 V, V_{SENSE} = 0 mV T_A = –40°C to 125°C)	**105**	125		dB
		NCx213R		**100**	120		
V_{OS}	Input Offset Voltage (Note 7)	NCx210R, NCx211R	V_{SENSE} = 0 mV		±0.55	±35	µV
		NCx213R			±5	±100	
		NCx214R			±1	±60	
dV_{OS}/dT	Input Offset Voltage Drift over Temperature (Note 7)	NCx21xR	V_{SENSE} = 0 mV T_A = –40°C to +125°C		±0.1	**±0.5**	µV/°C
PSRR	Power Supply Rejection Ratio, RTI (Note 7)		V_S = +2.7 V to +26 V, V_{IN+} =18 V, V_{SENSE} = 0 mV		±0.1	±10	µV/V
I_{IB}	Input Bias Current		V_{SENSE} = 0 mV		±39	±60	µA
I_{IO}	Input Offset Current		V_{SENSE} = 0 mV		±0.1		µA
OUTPUT							
G	Gain	NCx210R			200		V/V
		NCx211R			500		
		NCx213R			50		
		NCx214R			100		
E_G	Gain Error	NCx21xR	V_{SENSE} = –5 mV to 5 mV, T_A = –40°C to 125°C		±0.2	**±1**	%
E_G	Gain Error vs Temperature	NCx21xR	T_A = –40°C to 125°C		±3	**±10**	ppm/°C
	Nonlinearity Error		V_{SENSE} = –5 mV to 5 mV		±0.01		%
C_L	Maximum Capacitive Load		No sustained oscillation		1		nF
VOLTAGE OUTPUT							
V_{OH}	Swing to V_S Power Supply Rail		R_L = 10 kΩ to GND T_A = –40°C to +125°C (Note 8)		V_S – 0.075	**V_S – 0.2**	V
V_{OL}	Swing to GND		R_L = 10 kΩ to GND T_A = –40°C to +125°C		V_{GND} +0.005	**V_{GND} +0.05**	V
FREQUENCY RESPONSE							
BW	Bandwidth (f_{-3dB})	NCx210R	C_{LOAD} = 10 pF		40		kHz
		NCx211R			25		
		NCx213R			90		
		NCx214R			60		
SR	Slew Rate				1		V/µs
NOISE							
e_n	Voltage Noise Density (Note 7)		f = 1 kHz		45		nV/√Hz
POWER SUPPLY							
V_S	Operating Voltage Range		T_A = –40°C to +125°C	**2.2**		**26**	V
I_Q	Quiescent Current		V_{SENSE} = 0 mV		40	80	µA
	Quiescent Current over Temperature		T_A = –40°C to +125°C			**100**	µA

Typical Application

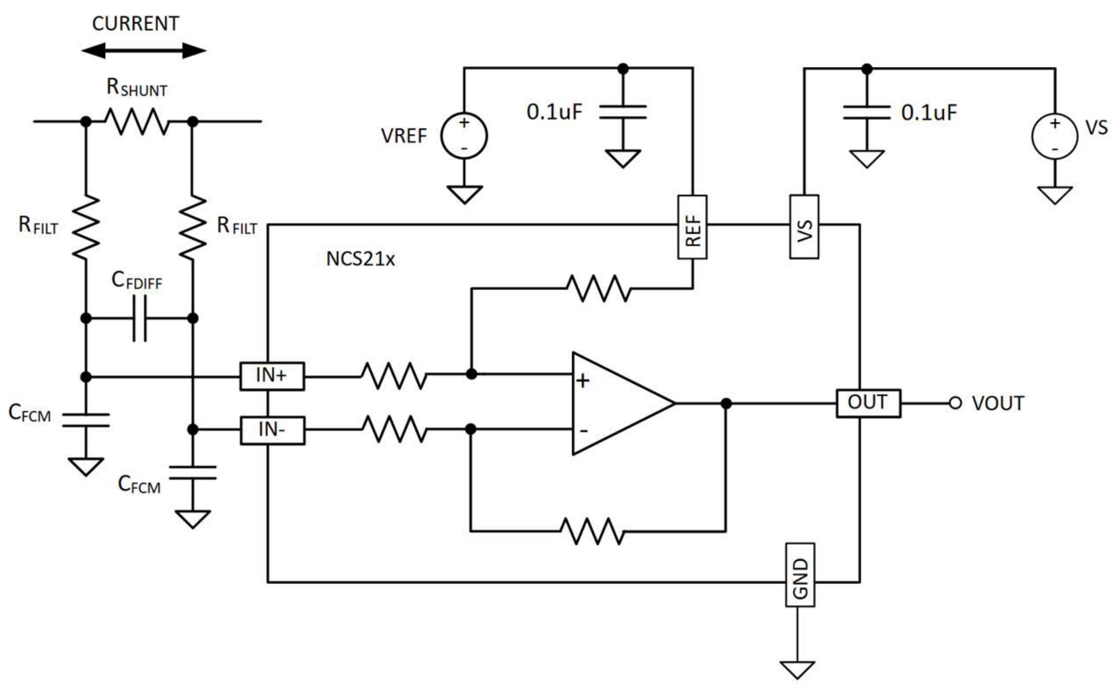
- Here we see a schematic of a typical shunt based current sense application. We see the common connections to the current sense amplifier including the plus and shunt voltage inputs, Vs Supply, VREF zero current reference voltage input, and the Output voltage. The example shown is the NCS21x current sense amplifier which offers devices with gains of 50, 100, 200 and 500.
- This example show a Bi-directional application where current will flow in both direction in the shunt resistor. The VREF voltage sets the output voltage when zero current flows in the shunt. Uni-direction amplifiers internally connect the VREF terminal to GND



onsemi

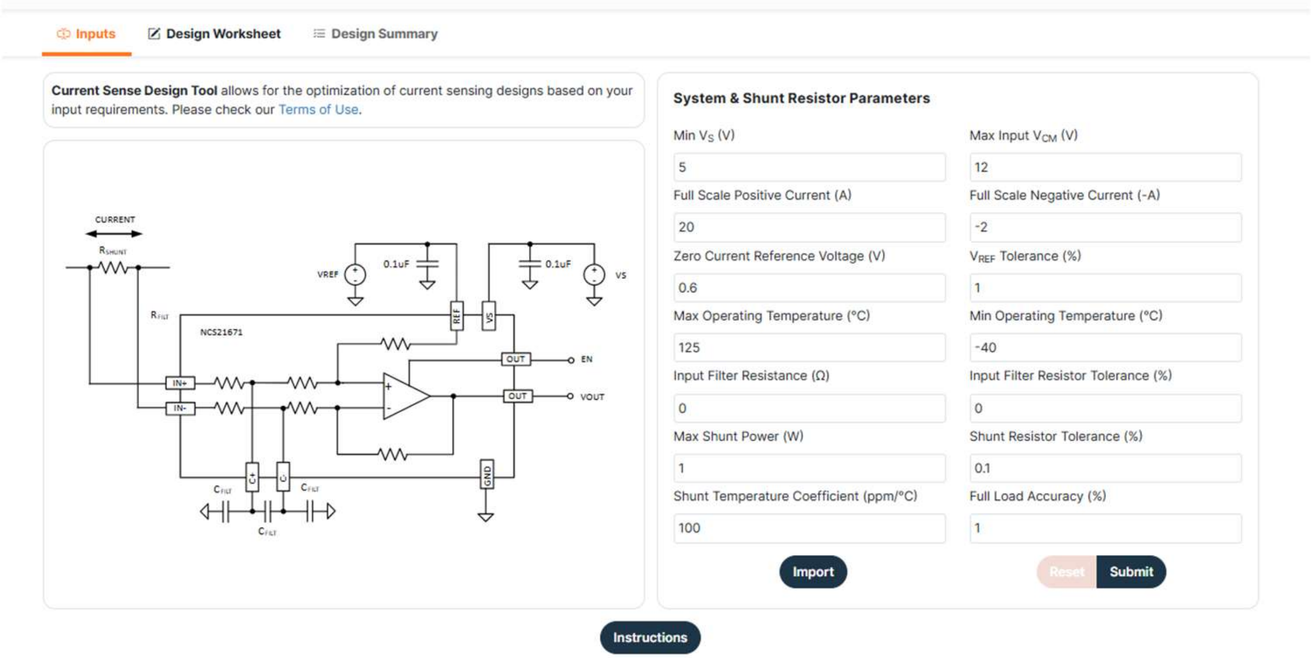
Typical Application

- The amplifier itself consists of a low offset zero drift amplifier topology with matched internal feedback components to form a highly accurate fixed gain amplifier. The VS supply voltage sets the full-scale output voltage. All current readings are scaled between GND and VS potential with some output stage limits incorporated into the tool.



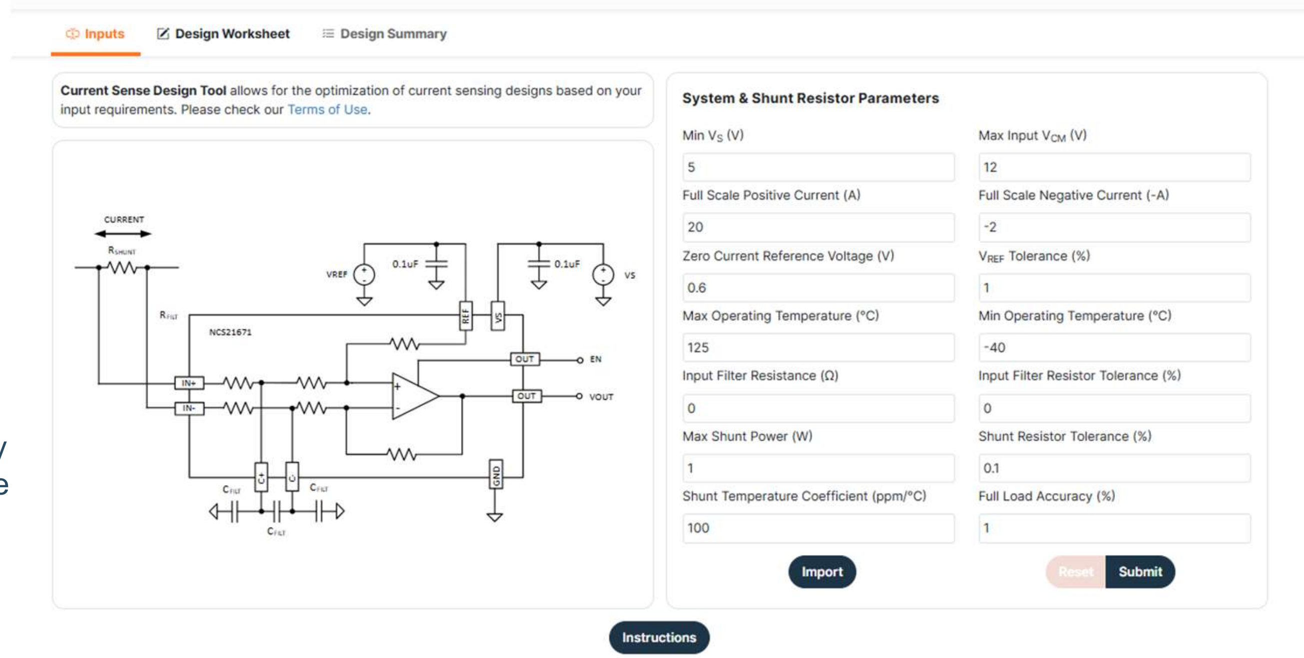
Inputs Page

- The input page is where we enter key known system requirements for the current sense circuit. Many of these inputs are well known to the system designer such as VS supply, input common mode voltage.
- You will need to enter the full scale positive and negative current range in amps. The tool will use these values to suggest devices and exclude devise based on current directionality. A full-scale negative current of anything other than zero will exclude unidirectional devices from recommendation.
- Reference voltage and tolerance must be calculated separately and entered here
- Temperature ranges are specifically relating to the amplifier die temperature and will generally be that of the system board temperature since the amplifier itself is largely non-dissipative. If the shunt is placed close to the device which is typically recommended, the heating effects of the shunt on that region of the PCB should be considered and the temperature value adjusted accordingly



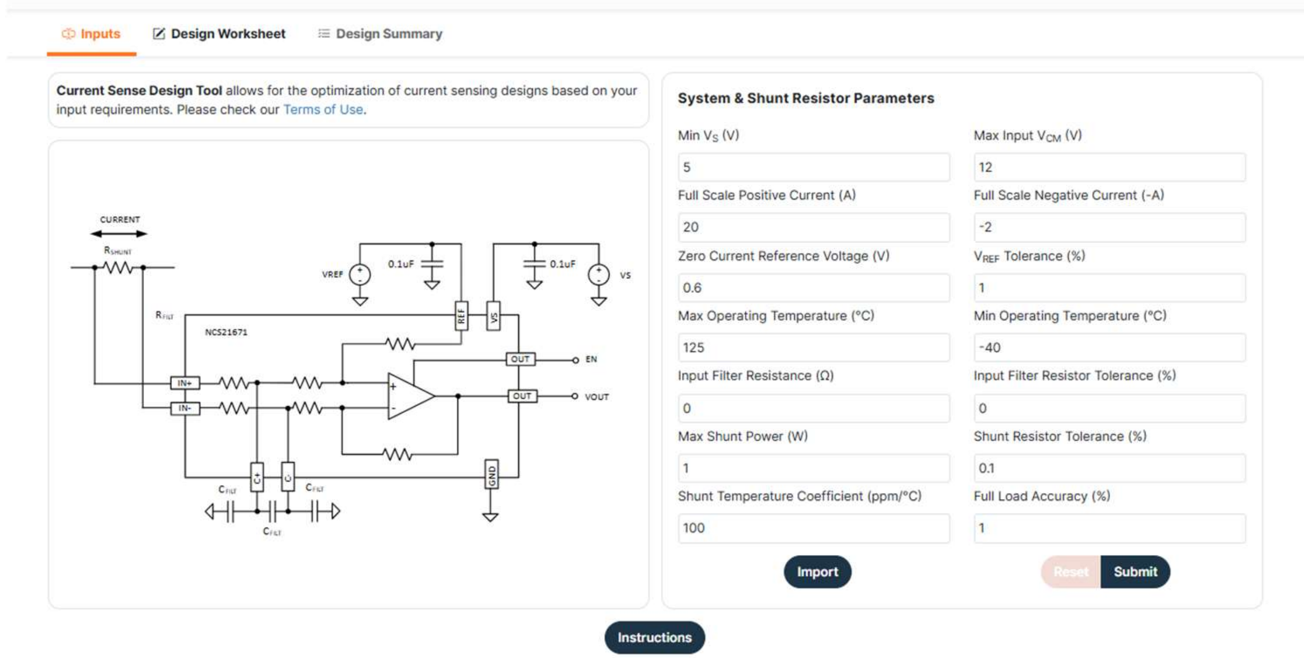
Inputs Page

- It should be noted that this tool is a DC error calculator and does not incorporate common or differential mode input transient voltages. This is too system specific to incorporate in in a generic calculator. However, some systems may need to incorporate input filtering to keep noise out of the measurements and keep the device inputs within specifications. This can be implemented as either common mode with two capacitors to ground, or differential with one capacitor across the inputs, or both. In either case input resistors must be used in series with each input to form the filter. Addition of theses resistors and their tolerance will add error tie the sensed current. They will reduce the gain by modifying the overall input impedance and they are not temperature matched to the amplifier's input impedance, so there will be temperature induced error as well. These factors are integrated into the tool, and you can enter the resistor value and tolerance accordingly to see these effects. Industry standard has been to advise against values grater than a given amount. This tool allows you to see the effects directly.



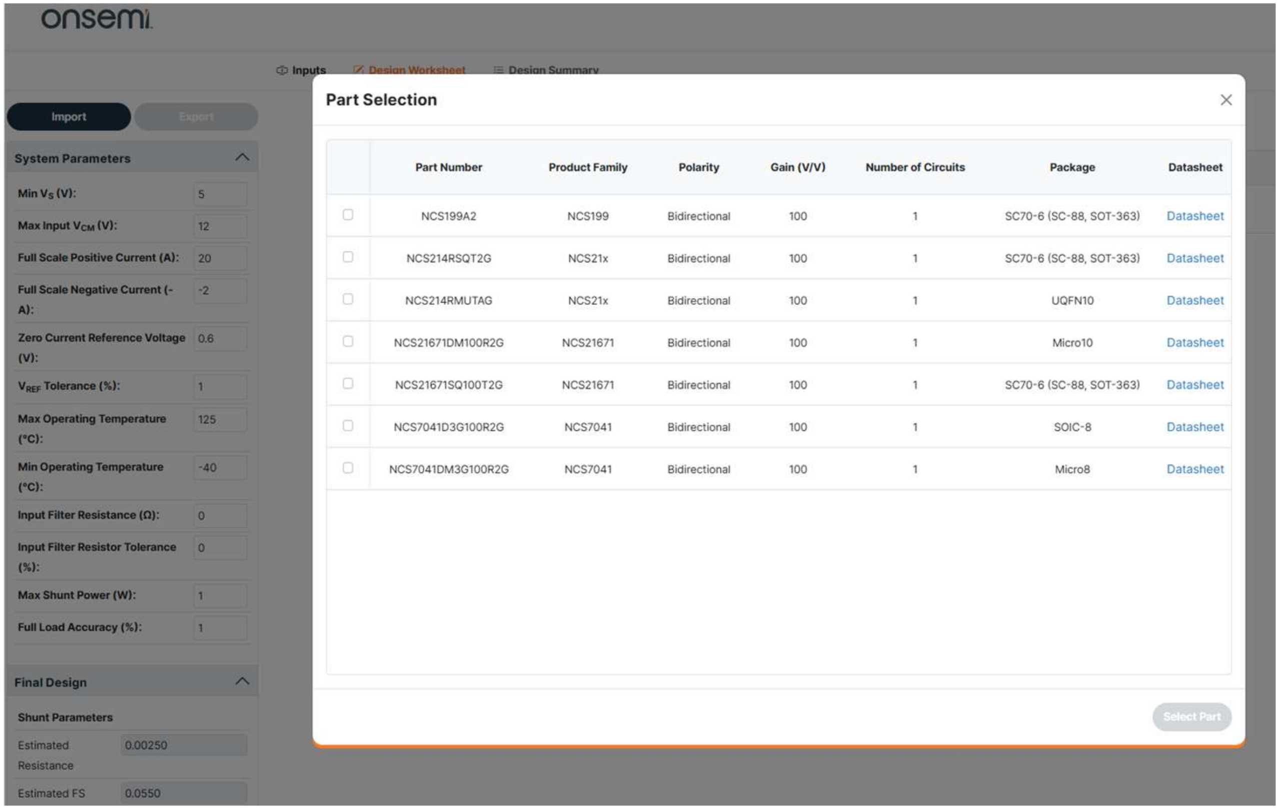
Inputs Page

- Now to the most important entry which is the shunt power, shunt tolerance and shunt temperature coefficient. The tool will recommend a shunt value and devices with appropriate gain to fit within the power budget and meet the full-scale current. Don’t worry if you don’t have exact values initially, these can be refined later. This is a first approximation at a solution for you to refine later.
- Finally, you enter the desired light and full load accuracy the tool does not exclude devices that do not meet these accuracies, but the design and summary pages will highlight in red if you are net meeting these requirements and you an refine the design until you are in specification.
- Once we fully enter the system inputs we can enter submit to go to the Design Worksheet page.
- Notice there are some other buttons as well. Reset will bring all values to the default values.
- The Design worksheet page will allow you to save a design in a local file which can be uploaded here or in the Design worksheet



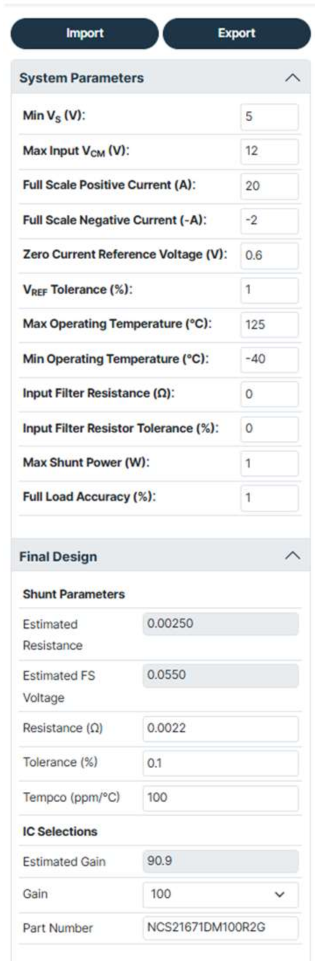
Design Worksheet Page

- Once you hit submit, the part selection window will pop up allowing you to select a recommended amplifier. Here you can typically select from a number devices that might fit the design. A gain has been selected, and package options are shown. Links to the specific datasheets are included to help selection at this stage.
- Highlight a device and hit Select Part



Design Worksheet Page

- Once a part has been selected you enter the Design Worksheet page. Here we see a basic schematic of the device in application with available package and pinout options for reference.
- To the upper left we see a summary of the inputs page with options to change their values.
- To the lower left we have the shunt parameters and IC selection available for modification. The tool has selected an appropriate gain and shunt resistance for the inputs specified. Shunt value, tolerance and tempco can be iterated to optimize the design.
- All parameters for the design can be exported and imported using the export and import buttons



Import | Export

System Parameters

Min V_S (V):	5
Max Input V_{CM} (V):	12
Full Scale Positive Current (A):	20
Full Scale Negative Current (-A):	-2
Zero Current Reference Voltage (V):	0.6
V_{REF} Tolerance (%):	1
Max Operating Temperature (°C):	125
Min Operating Temperature (°C):	-40
Input Filter Resistance (Ω):	0
Input Filter Resistor Tolerance (%):	0
Max Shunt Power (W):	1
Full Load Accuracy (%):	1

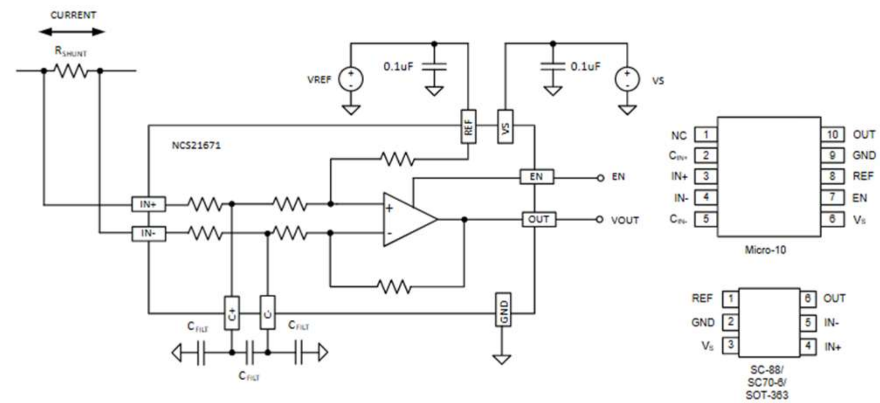
Final Design

Shunt Parameters

Estimated Resistance	0.00250
Estimated FS Voltage	0.0550
Resistance (Ω)	0.0022
Tolerance (%)	0.1
Tempco (ppm/°C)	100

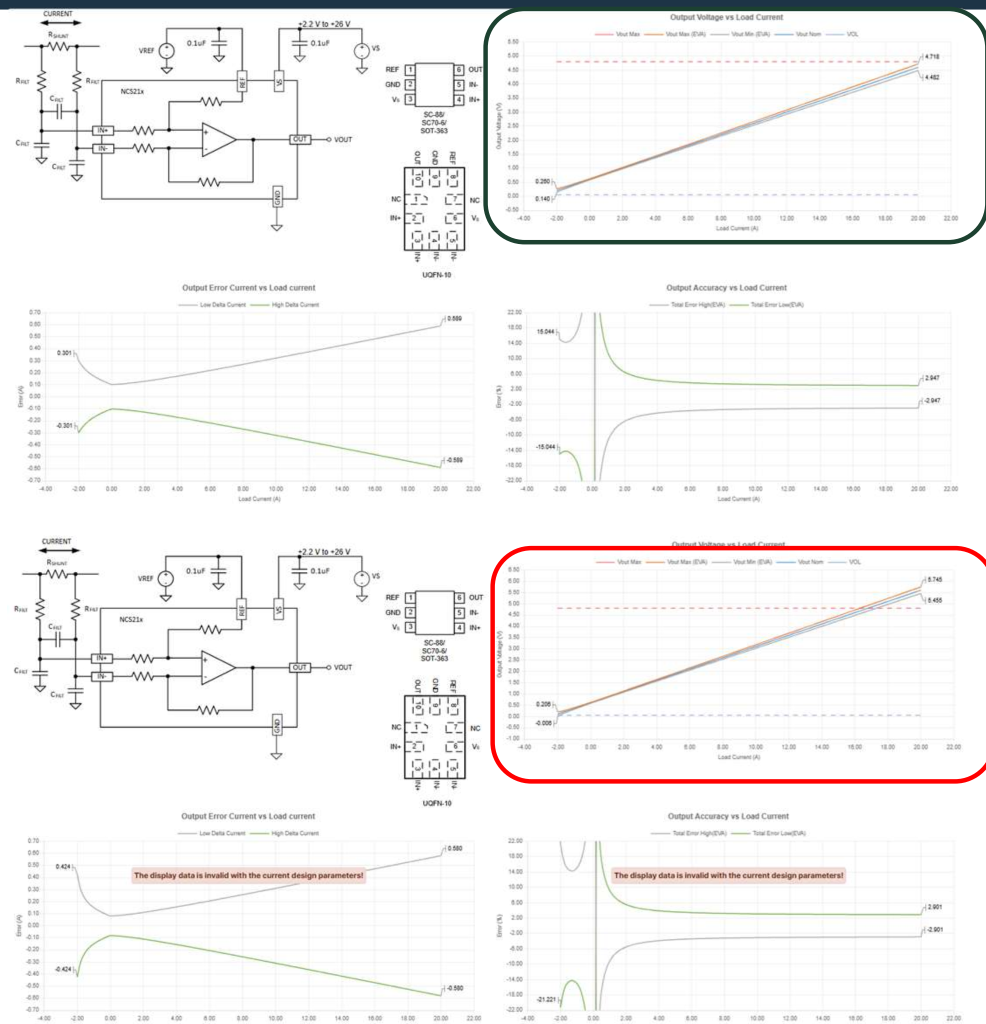
IC Selections

Estimated Gain	90.9
Gain	100
Part Number	NCS21671DM100R2G



Design Worksheet Page

- The goal is to arrive at component values for the design that meet the error budget and power budget for the system. Three curves are provided to aid in this process the first and most important curve in the upper right corner displays the nominal output voltage with the upper and lower worst case boundary voltages. It is important to change shunt value or device gain to maximize the window of operation (VS to ground) while not allowing the boundary values to exceed the limit lines. If the output exceeds the output limits error warnings are displayed over the error curves. You must keep the output within these boundaries for the curves to be valid. These examples show in bound and out of bounds conditions for reference. Here the shunt resistance is too high forcing the output to extend beyond the VS voltage which is not possible.
- Design Issues will display at the top as well to alert what is wrong with the chosen parameters.



Design Worksheet Page

Design Issues

- **VFS (V):** VFS (V) is greater than V_{OUT} Max (V).
- **Scale Utilization (%):** Scale utilization is greater than 1.
- **Output Voltage Range:** The maximum output voltages are outside the selected part's specified range (Maximum: 4.9650 V).

Design Estimations

VFS (V)	Shunt Power (w)	Full Scale Error: EVA (%)	Full Scale Current(A)	Scale Utilization (%)	Nominal Gain With Filter
5.08 (!)	0.880	1.91	20.0	102 (!)	0.00220

Spec Limits (Product Page | Datasheet)

Gain Error 25°C	Gain Error vs Temp Spec	Gain Error vs Temp	Overall Gain Error	V_{OS} RTI	V_{OS} Temp Drift RTI	RTI CMRR RTI	V_{OS} CM	V_{OS} Total
-0.00825	0.500	0.00825	0.00	0.0000100	0.0000825	109	0.0000426	0.0000925

- Design Estimates are shown at the top for a summary. Out of spec conditions will be highlighted with an exclamation point in a circle. Here the output voltage exceeds the VS voltage triggering a VFS (Voltage Full-Scale) error. Scale utilization is the percentage of the Full-Scale voltage is utilized. Values greater that 100% will trigger an error.
- In this case, the shunt resistor is reduced to reduce the gain fit the Full-Scale Voltage window.

Design Estimations

VFS (V)	Shunt Power (w)	Full Scale Error: EVA (%)	Full Scale Current(A)	Scale Utilization (%)	Nominal Gain With Filter
4.68	0.800	1.93	20.0	94.2	0.00200

Spec Limits (Product Page | Datasheet)

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Design Worksheet Page

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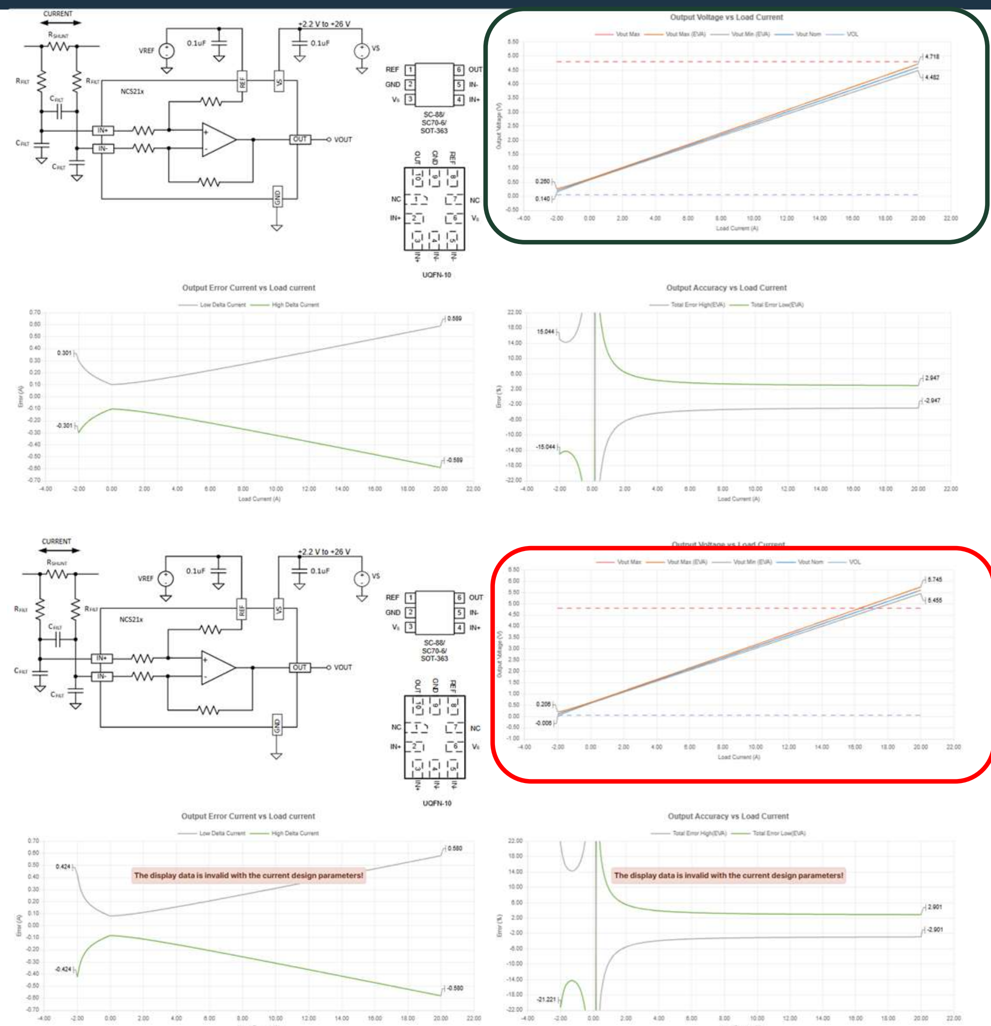
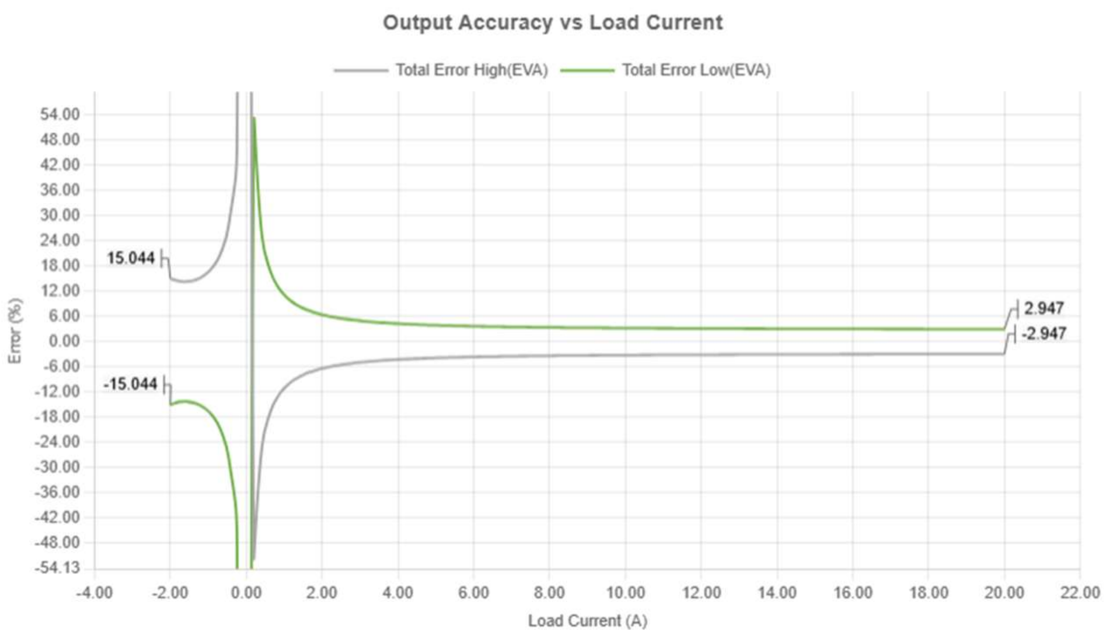


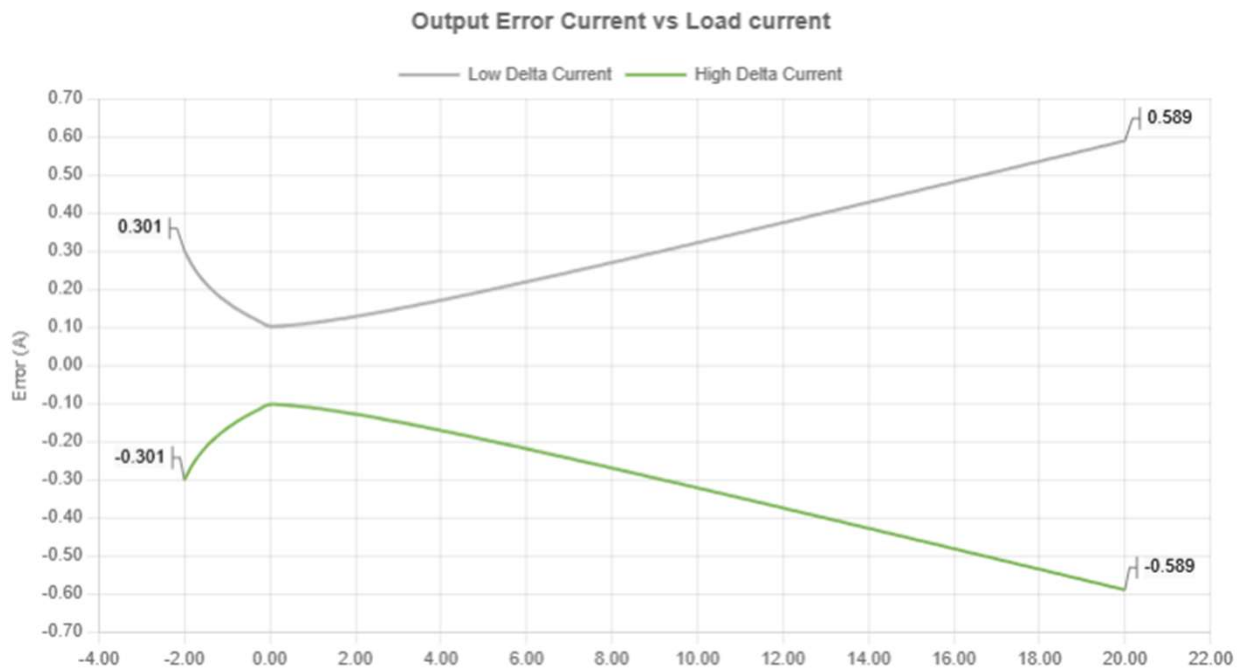
Error curves

- The Industry standard has been to specify current sense accuracy in the form of % error from nominal. This is effective when discussion full and medium load currents, but has an unavoidable issue at and near zero load current. Divide by zero creates asymptotic error values which are not useful if you are interested in knowing the error near zero current. Non the less this error curve is included in the result (asymptotes and all)



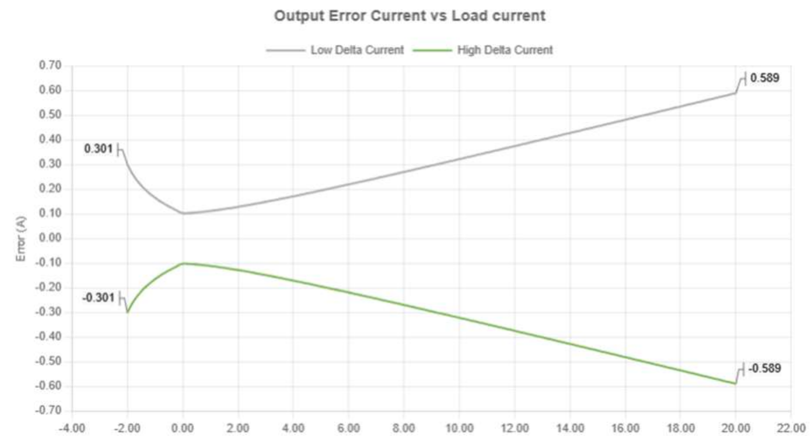
Error curves

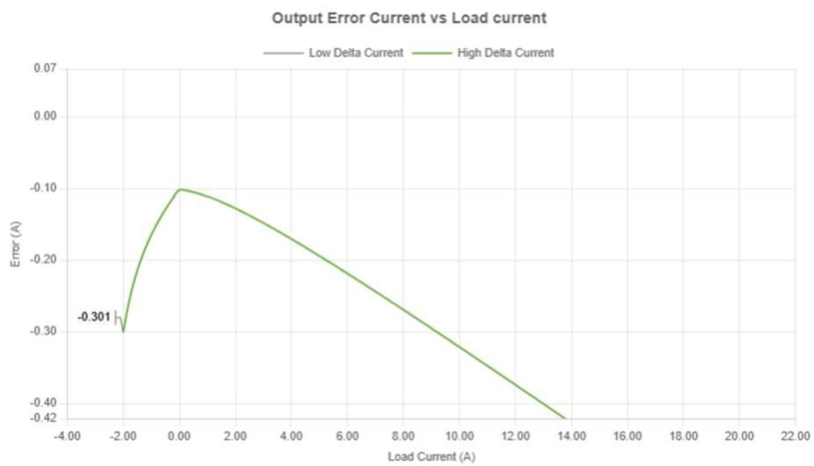
- However, a more consist error evaluation can be made that avoids infinities near zero. The curve on the right expresses the equivalent current error window vs load current in terms of current. That is, “to what level can we resolve current in amps at a given current.” At zero load the output voltage is governed strictly by input offset voltage. Offset is finite and unavoidable. The output voltage window driven by offset at zero current dictates a minimum current error translated to real amps assuming ideal shunt resistance and amp gain.
- If we measure 100mV at 0A load due to offset, the system will be evaluating that voltage as real current. A 100mohm shunt, gain 100 current system could appear to be measuring 10mA when the current is actually 0A. (100mV/100/10mOhm = 10mA) This means we can only resolve current down to 100mA of accuracy in this system
- As other errors enter the picture at higher load current we see degraded current resolution extending to higher current in both directions. In this case, we can only resolve current to +/- 589mA at 20A.



Other Features

- Holding Cntr and rolling the mouse wheel enables zoom in and zoom out at the page level
- Holding the Alt key and rolling the mouse wheel enables zoom in and zoom out on all curves.





Design Summary

- The Design summary page shows Design Specifications, Shunt Characteristics, Designs results and the selected amplifier part specifications along with the schematic and error curves.
- Printing this page formats well in a PDF letter format.

Inputs | Design Worksheet | Design Summary

Design Specification

Min V_S (V)	Max Input V_{CM} (V)	Full Load Accuracy (%)	Full Scale Positive Current (A)	Full Scale Negative Current (-A)	Zero Current Reference Voltage (V)	V_{REF} Tolerance (%)
5.00	12.0	2.00	20.0	-2.00	0.600	1.00

Min Operating Temperature (°C)	Max Operating Temperature (°C)	Input Filter Resistance (Ω)	Input Filter Resistor Tolerance (%)	Input Filter Resistor Tempco (ppm/°C)
-40.0	125	0.00	0.00	100

Shunt Resistor

Resistance (Ω)	Tolerance (%)	Tempco (ppm/°C)
0.00200	0.100	100

Design Estimation

VFS (V)	Shunt Power (w)	Full Scale Error: EVA (%)	Full Scale Current(A)	Scale Utilization (%)	Nominal Gain With Filter
4.68	0.800	1.93	20.0	94.2	0.00200

Part Information

Part Number	Datasheet	Polarity	Gain (V/V)	Number of Circuits	Package	CMRR RTI (dB)	Max V_{CM} (V)	Typ V_{OS}	V_{OS} Max RTI: V_{CM} 12V	V_{OS} Max RTI: V_{CM} 0V	V_{OS} Max Drift (V)
NCS21671DM100R2G	Link	Bidirectional	100	1	Micro10	109	40.0	0.00000300	0.0000100	N/A	5.00e-7

Gain Error Typ	Gain Error: Full Temperature	Gain Drift (ppm/°C)	RFB2 (Ω)	V_{OH} (V)	V_{OL} (V)
N/A	0.00	0.500	1.00e+6	0.0350	0.00200

Other things to look out for

- Some current sense applications may have a particularly noisy common mode signal or high peak differential currents embedded in the DC which you may want to filter out. This can be done by adding simple RC filters at the IN+ and IN- terminals as shown
- Series resistors in combination with C_{FDIFF} and/or C_{FCMIFF} form a low pass filter. It should be noted that doing so will degrade performance by adding unmatched increased input resistance to the fixed divider feedback within the device. Adding resistance will reduce the nominal gain and add temperature drift error.
- This effect is incorporated into the tool for system designers to evaluate. This is better than just suggesting not to use a value greater than "x" which is what most datasheet suggest. Here if there is a more desirable resistor or capacitor, we can evaluate the results.
- In this case we can see that adding a 50 Ohm resistor has shifted the error curves down resulting in asymmetric positive and negative error values for a given current.
- The tool limits values to 50 ohms.