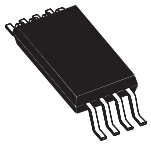
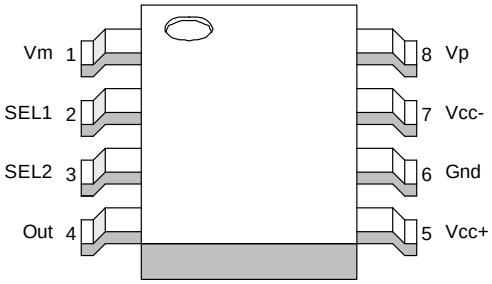
CS70

High side current sense high voltage op amp

Datasheet - production data



TSSOP8
(Plastic package)



Pin connections
(top view)

Features

- Independent supply and input common-mode voltages
- Wide common-mode operating range: 2.9 V to 70 V in single-supply configuration, -2.1 V to 65 V in dual-supply configuration
- Wide common-mode surviving range: -16 V to 75 V (reversed battery and load-dump conditions)
- Supply voltage range: 2.7 to 5.5 V in single-supply configuration
- Low current consumption: I_{CC} max = 360 µA
- Pin selectable gain: 20 V/V, 25 V/V, 50 V/V or 100 V/V
- Buffered output

Applications

- Wireless battery chargers
- Chargers for portable equipment
- Precision current sources
- Wearable

Description

The CS70 measures a small differential voltage on a high-side shunt resistor and translates it into a ground-referenced output voltage. The gain is adjustable to four different values from 20 V/V up to 100 V/V by two selection pins.

Wide input common-mode voltage range, low quiescent current, and tiny TSSOP8 packaging enable use in a wide variety of applications.

The input common-mode and power-supply voltages are independent. The common-mode voltage can range from 2.9 V to 70 V in the single-supply configuration or be offset by an adjustable voltage supplied on the Vcc- pin in the dual-supply configuration.

With a current consumption lower than 360 µA and a virtually null input leakage current in standby mode, the power consumption in the applications is minimized.

Table 1. Device summary

Part number	Temperature range	Package	Packaging	Marking
CS70P	- 40° C to +125 °C	TSSOP8	Tape and reel	103I

Contents

1 Application schematic and pin description

The CS70 high-side current sense amplifier can be used in either single- or dual-supply mode. In the single-supply configuration, the CS70 features a wide 2.9 V to 70 V input common-mode range totally independent of the supply voltage. In the dual-supply range, the common-mode range is shifted by the value of the negative voltage applied on the Vcc- pin. For instance, with Vcc+ = 5 V and Vcc- = -5 V, then the input common-mode range is -2.1 V to 65 V.

Figure 1. Single-supply configuration schematic

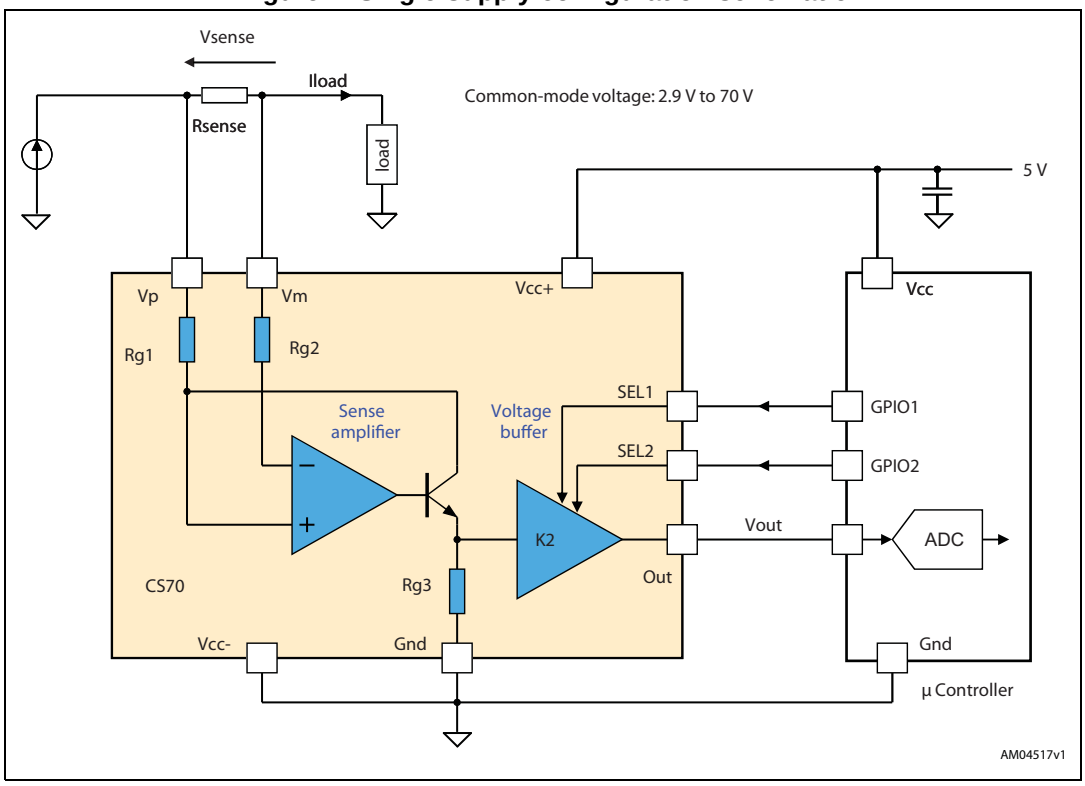


Figure 2. Dual-supply configuration schematic

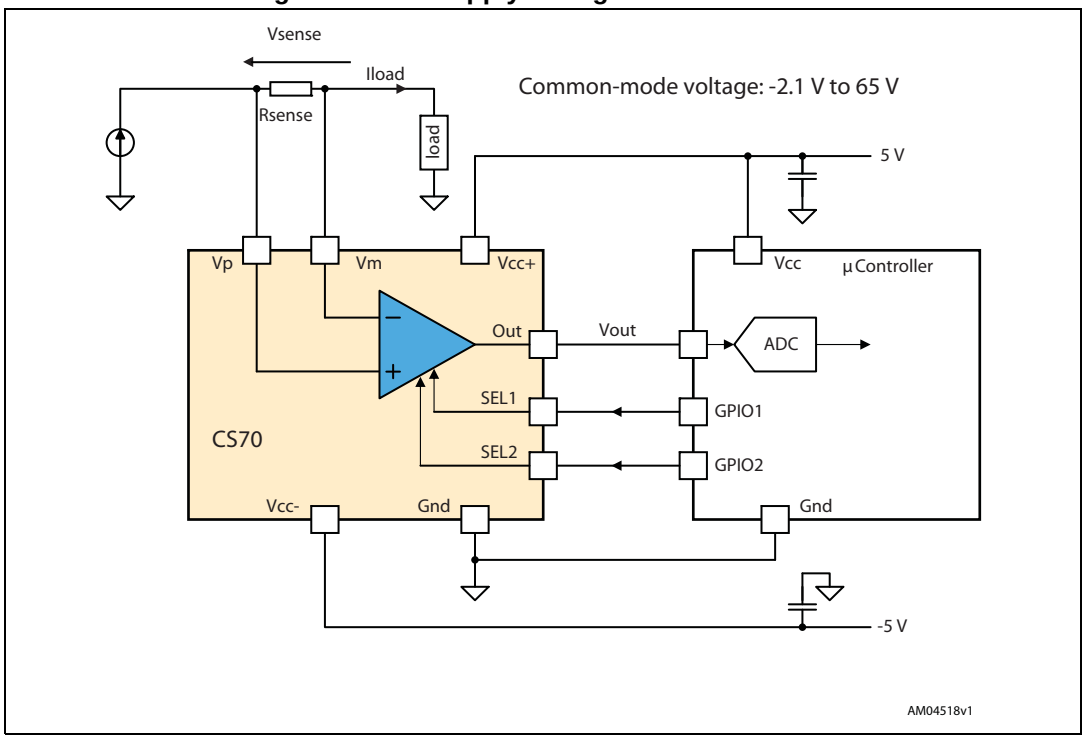


Figure 3. Common-mode versus supply voltage in dual-supply configuration

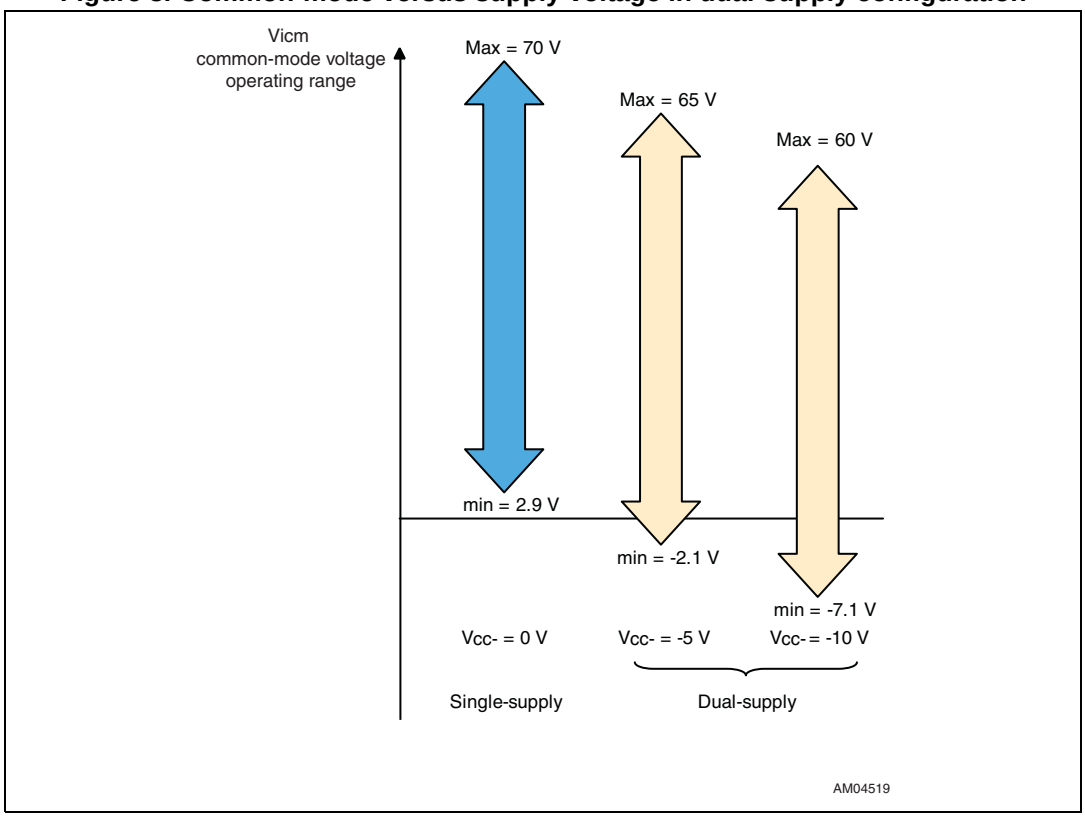


Table 2 describes the function of each pin. Their position is shown in the illustration on the cover page and in *Figure 1 on page 3*.

Table 2. Pin description

Symbol	Type	Function
Out	Analog output	The Out voltage is proportional to the magnitude of the sense voltage V_p-V_m.
Gnd	Power supply	Ground line
Vcc+		Positive power supply line.
Vcc-		Negative power supply line.
Vp	Analog input	Connection for the external sense resistor. The measured current enters the shunt on the V_p side.
Vm		Connection for the external sense resistor. The measured current exits the shunt on the V_m side.
SEL1	Digital input	Gain-select pin
SEL2		

2 Absolute maximum ratings and operating conditions

Table 3. Absolute maximum ratings

Symbol	Parameter	Value	Unit
V_{id}	Input pins differential voltage (V_p-V_m)	±20	V
V_{in_sense}	Sensing pins input voltages (V_p, V_m)(1)	-16 to 75	
V_{in_sel}	Gain selection pins input voltages (SEL1, SEL2)(2)	-0.3 to V_{cc+}+0.3	
V_{cc+}	Positive supply voltage(2)	-0.3 to 7	
V_{cc+}-V_{cc-}	DC supply voltage	0 to 15	
V_{out}	DC output pin voltage(2)	-0.3 to V_{cc+}+0.3	
T_{stg}	Storage temperature	-55 to 150	°C
T_j	Maximum junction temperature	150	
R_{thja}	TSSOP8 thermal resistance junction to ambient	120	°X/Ω
	SO8 thermal resistance junction to ambient	125	
ESD	HBM: human body model(3)	2.5	kV
	MM: machine model(4)	150	V
	CDM: charged device model(5)	1.5	kV

1. These voltage values are measured with respect to the Vcc- pin.
2. These voltage values are measured with respect to the Gnd pin.
3. Human body model: a 100 pF capacitor is charged to the specified voltage, then discharged through a 1.5 kΩ resistor between two pins of the device. This is done for all couples of connected pin combinations while the other pins are floating.
4. Machine model: a 200 pF capacitor is charged to the specified voltage, then discharged directly between two pins of the device with no external series resistor (internal resistor < 5 Ω). This is done for all couples of connected pin combinations while the other pins are floating.
5. Charged device model: all pins plus package are charged together to the specified voltage and then discharged directly to ground.

Table 4. Operating conditions

Symbol	Parameter	Value	Unit
V_{cc+}	Supply voltage in single-supply configuration from T_{min} to T_{max} (V_{cc-} connected to Gnd = 0 V)	2.7 to 5.5	V
V_{cc-}	Negative supply voltage in dual-supply configuration from T_{min} to T_{max}	-	V
	V_{cc+} = 5.5 V max	-8 to 0	
	V_{cc+} = 3 V max	-11 to 0	
V_{icm}	Common-mode voltage range referred to pin Vcc - (T_{min} to T_{max})	2.9 to 70	V
T_{oper}	Operational temperature range (T_{min} to T_{max})	-40 to 125	°C

3 Electrical characteristics

The electrical characteristics given in the following tables are measured under the following test conditions unless otherwise specified.

- T_{amb} = 25 °C, V_{cc+} = 5 V, V_{cc-} connected to Gnd (single-supply configuration).
- $V_{sense} = V_p - V_m$ = 50 mV, V_m = 12 V, no load on Out, all gain configurations.

Table 5. Supply

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
I_{CC}	Total supply current	V_{sense} = 0 V, $T_{min} < T_{amb} < T_{max}$	-	200	360	µA
I_{CC1}	Total supply current	V_{sense} = 50 mV Av = 50 V/V $T_{min} < T_{amb} < T_{max}$		300	480	

Table 6. Input

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
DC CMR	DC common-mode rejection Variation of V_{out} versus V_{icm} referred to input(1)	2.9 V< V_m < 70 V $T_{min} < T_{amb} < T_{max}$	90	105		dB
AC CMR	AC common-mode rejection Variation of V_{out} versus V_{icm} referred to input (peak-to-peak voltage variation)	Av = 50 V/V or 100 V/V 2.9 V< V_m < 30 V 1 kHz sine wave		95		
SVR	Supply voltage rejection Variation of V_{out} versus V_{CC}(2) SEL1 = Gnd, SEL2 = Gnd	2.7 V< V_{CC} < 5.5 V V_{sense} = 30 mV $T_{min} < T_{amb} < T_{max}$	85	95		
V_{os}	Input offset voltage(3)	T_{amb} = 25 °C $T_{min} < T_{amb} < T_{max}$			±500 ±1100	µV
dV_{os}/dT	Input offset drift vs. T	Av = 50 V/V $T_{min} < T_{amb} < T_{max}$	-20		+5	µV/°C
I_{lk}	Input leakage current	V_{CC} = 0 V $T_{min} < T_{amb} < T_{max}$			1	µA
I_{ib}	Input bias current	V_{sense} = 0 V $T_{min} < T_{amb} < T_{max}$		10	15	
V_{IL}	Logic low voltage threshold (SEL1 and SEL2)	$V_{CCmin} < V_{CC} < V_{CCmax}$ $T_{min} < T_{amb} < T_{max}$	-0.3		0.5	V
V_{IH}	Logic high voltage threshold (SEL1 and SEL2)	$V_{CCmin} < V_{CC} < V_{CCmax}$ $T_{min} < T_{amb} < T_{max}$	1.2		V_{CC}	
I_{sel}	Gain-select pins (SEL1 and SEL2) input bias current	SEL pin connected to GND or V_{CC} $T_{min} < T_{amb} < T_{max}$		400		nA

1. See *Section 5: Parameter definitions* for the definition of CMR.
2. See *Section 5* for the definition of SVR.
3. See *Section 5* for the definition of V_{os}.

Table 7. Output

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
Av	Gain	SEL1 = Gnd, SEL2 = Gnd SEL1 = Gnd, SEL2 = Vcc+ SEL1 = Vcc+, SEL2 = Gnd SEL1 = Vcc+, SEL2 = Vcc+		20 25 50 100		V/V
$\Delta V_{out}/\Delta T$	Output voltage drift vs. T(1)	Av = 50 V/V $T_{min} < T_{amb} < T_{max}$			±240	ppm/°C
$\Delta V_{out}/\Delta I_{out}$	Output stage load regulation	-10 mA < I_{out} <10 mA I_{out} sink or source current Av = 50 V/V		0.3	±1.5	mV/mA
ΔV_{out}	Total output voltage accuracy(2)	V_{sense} = 50 mV(3) T_{amb} = 25 °C $T_{min} < T_{amb} < T_{max}$			±2.5 ±4	%
ΔV_{out}	Total output voltage accuracy	V_{sense} = 90 mV(3) T_{amb} = 25 °C $T_{min} < T_{amb} < T_{max}$			±3.5 ±5	
ΔV_{out}	Total output voltage accuracy	V_{sense} = 20 mV T_{amb} = 25 °C $T_{min} < T_{amb} < T_{max}$			±3.5 ±5	
ΔV_{out}	Total output voltage accuracy	V_{sense} = 10 mV T_{amb} = 25 °C $T_{min} < T_{amb} < T_{max}$			±5.5 ±8	
ΔV_{out}	Total output voltage accuracy	V_{sense} = 5 mV T_{amb} = 25 °C $T_{min} < T_{amb} < T_{max}$			±10 ±22	
I_{sc}	Short-circuit current	OUT connected to V_{CC} or GND	15	26		mA
V_{OH}	Output stage high-state saturation voltage $V_{OH} = V_{CC}-V_{out}$	V_{sense} = 1 V I_{out} = 1 mA		85	135	mV
V_{OL}	Output stage low-state saturation voltage	V_{sense} =-1 V I_{out} = 1 mA		80	125	

1. See *Section 5: Parameter definitions* for the definition of output voltage drift versus temperature.
2. Output voltage accuracy is the difference with the expected theoretical output voltage $V_{out\text{-}th}$=Av*V_{sense}. See *Section 5* for a more detailed definition.
3. Except for Av = 100 V/V.

Table 8. Frequency response

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
ts	Response to input differential voltage change. Output settling to 1% of final value	V_{sense} square pulse applied to generate a variation of Vout from 500 mV to 3 V C_{load} = 47 pF	-	-	-	µs
		Av = 20 V/V,		3		
		Av = 25 V/V		4		
		Av = 50 V/V		6		
		Av = 100 V/V		10		
t_{SEL}	Response to a gain change. Output settling to 1% of final value	Any change of state of SEL1 or SEL2 pin	-	1	-	µs
t_{rec}	Response to common-mode voltage change. Output settling to 1% of final value	V_{cc+}= 5 V, Vcc-= -5 V V_m step change from -2 V to 30 V or 30 V to -2 V		20		
SR	Slew rate	V_{sense} = 10 mV to 100 mV	0.4	0.6	-	V/µs
BW	3 dB bandwidth	C_{load} = 47 pF V_m = 12 V V_{sense} = 50 mV Av = 50 V/V	-	700	-	kHz

Table 9. Noise

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
e_N	Equivalent input noise voltage	f = 1 kHz	-	40	-	nV/$\sqrt{Hz}$

4 Electrical characteristics curves: current sense amplifier

Unless otherwise specified, the test conditions for the following curves are:

- T_{amb} = 25 °C, V_{CC} = 5 V, V_{sense} = V_p - V_m = 50 mV, V_m = 12 V
- No load on Out pin

Figure 4. Output voltage vs. Vsense

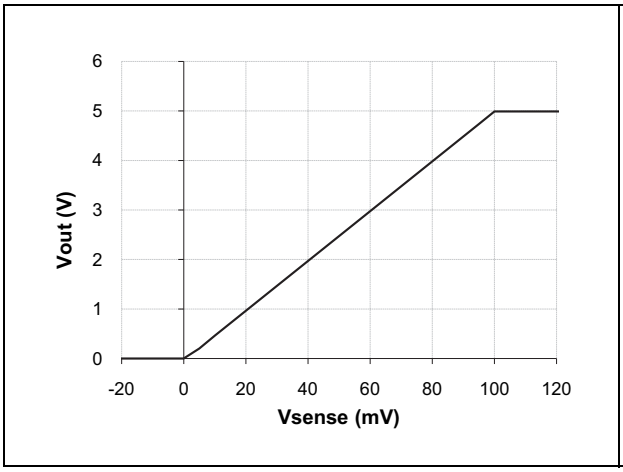


Figure 5. Output voltage accuracy vs. Vsense

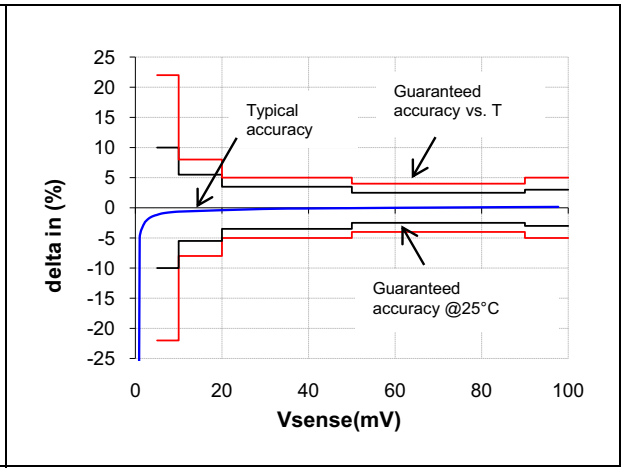


Figure 6. Supply current vs. supply voltage

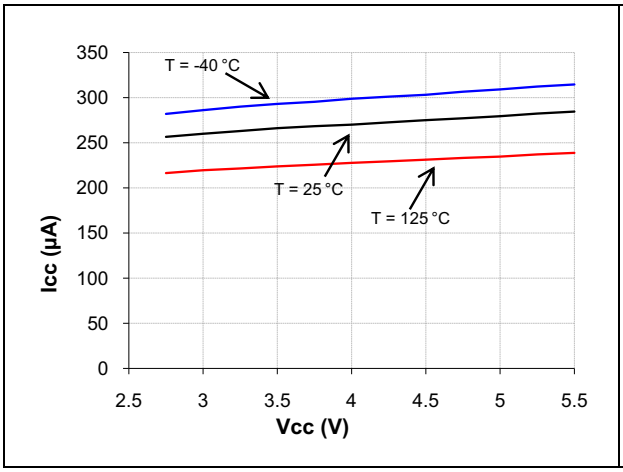


Figure 7. Supply current vs. Vsense

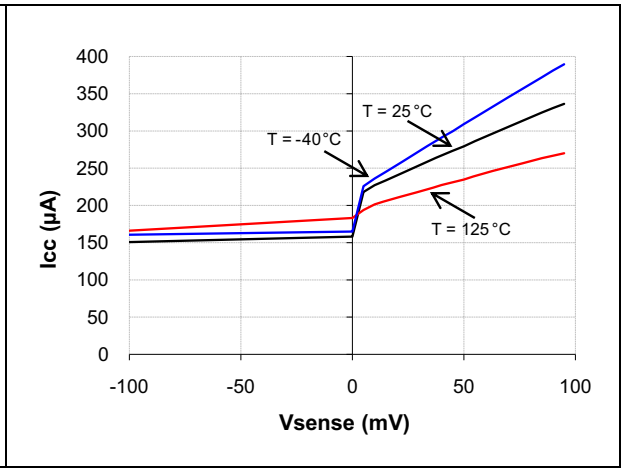


Figure 8. Vp pin input current vs. Vsense

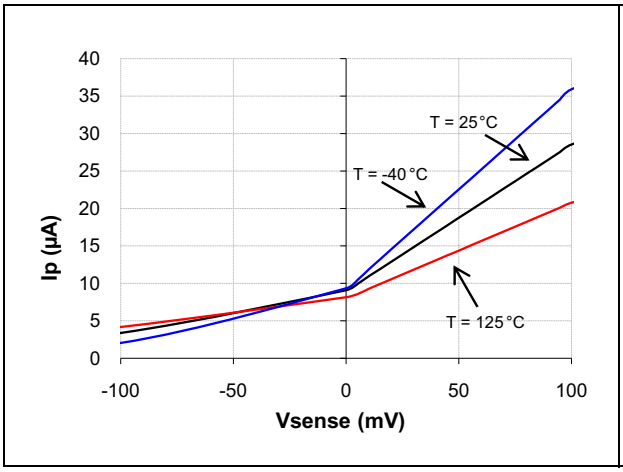


Figure 9. Vn pin input current vs. Vsense

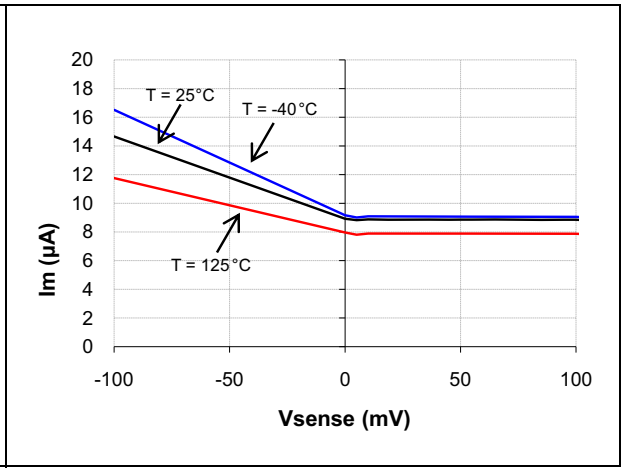


Figure 10. Output stage low-state saturation voltage vs. output current (V_{sense} = -1 V)

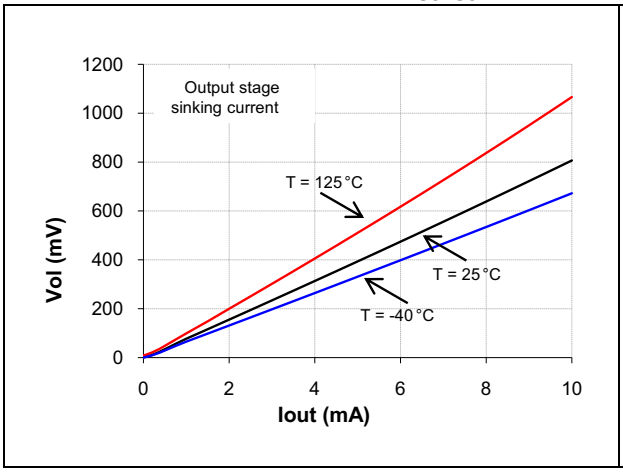


Figure 11. Output stage high-state saturation voltage vs. output current (V_{sense} = +1 V)

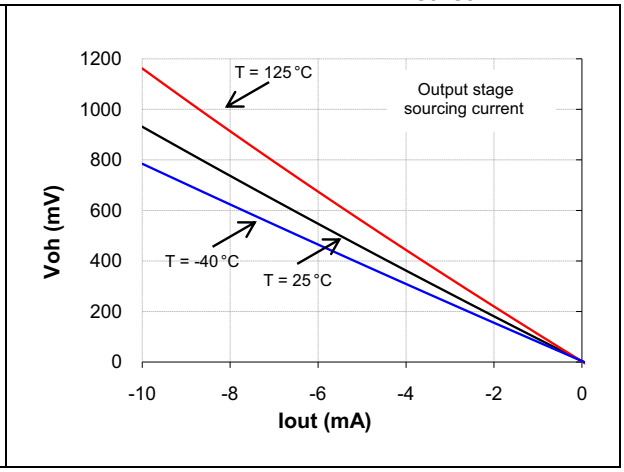


Figure 12. Output stage load regulation

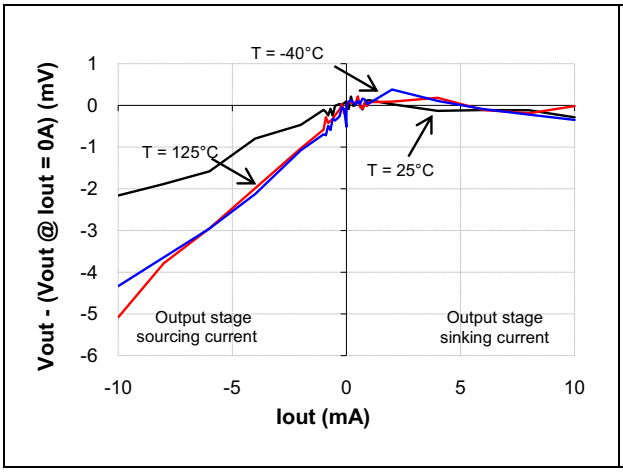


Figure 13. Step response

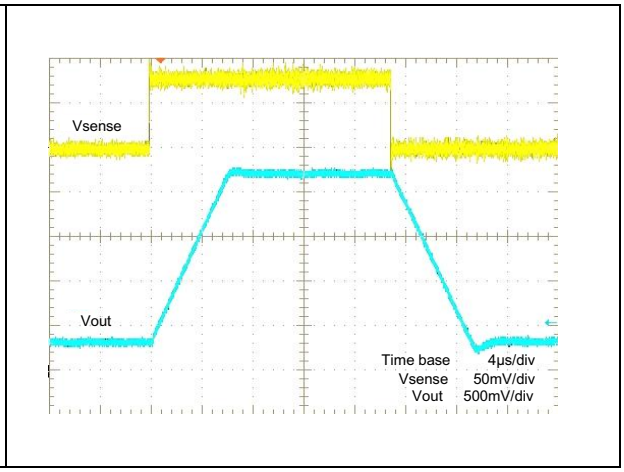


Figure 14. Bode diagram

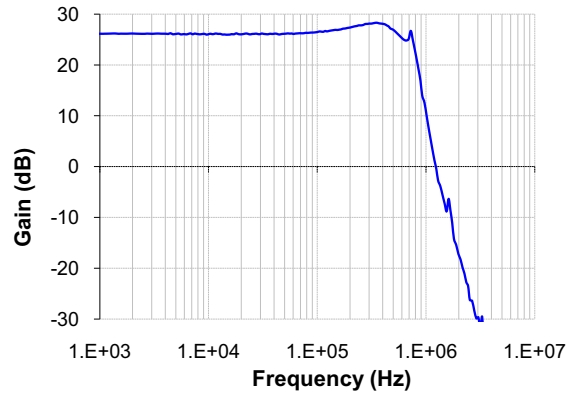


Figure 15. Power supply rejection ratio

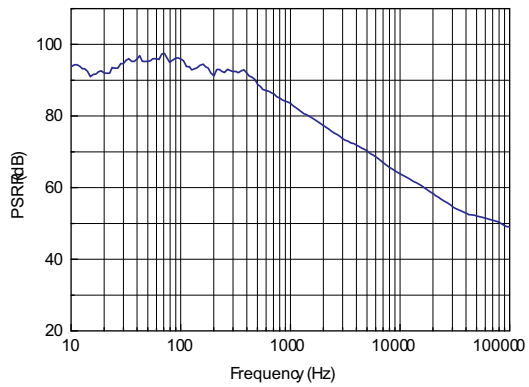
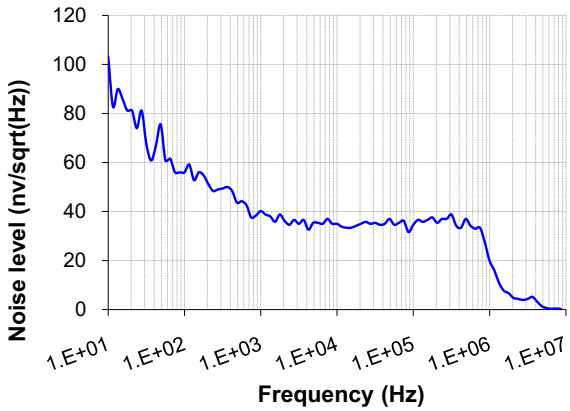


Figure 16. Noise level



5 Parameter definitions

5.1 Common-mode rejection ratio (CMR)

The common-mode rejection ratio (CMR) measures the ability of the current-sensing amplifier to reject any DC voltage applied on both inputs Vp and Vm. The CMR is referred back to the input so that its effect can be compared with the applied differential signal. The CMR is defined by the formula:

$$CMR = -20 \cdot \log \frac{\Delta V_{out}}{\Delta V_{icm} \cdot Av}$$

5.2 Supply voltage rejection ratio (SVR)

The supply-voltage rejection ratio (SVR) measures the ability of the current-sensing amplifier to reject any variation of the supply voltage V_{CC}. The SVR is referred back to the input so that its effect can be compared with the applied differential signal. The SVR is defined by the formula:

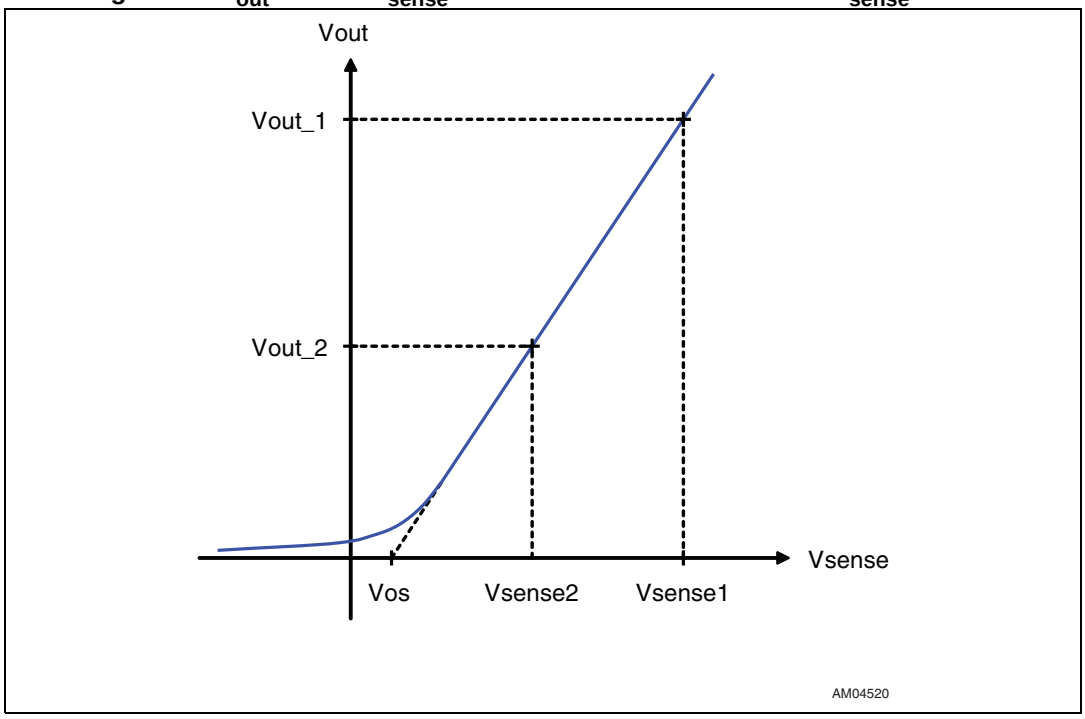
$$SVR = -20 \cdot \log \frac{\Delta V_{out}}{\Delta V_{CC} \cdot Av}$$

5.3 Gain (Av) and input offset voltage (V_{os})

The input offset voltage is defined as the intersection between the linear regression of the V_{out} vs. V_{sense} curve with the X-axis (see *Figure 17*). If V_{out1} is the output voltage with $V_{sense} = V_{sense1}$ and V_{out2} is the output voltage with $V_{sense} = V_{sense2}$, then V_{os} can be calculated with the following formula.

$$V_{os} = V_{sense1} - \left(\frac{V_{sense1} - V_{sense2}}{V_{out1} - V_{out2}} \cdot V_{out1} \right)$$

Figure 17. V_{out} versus V_{sense} characteristics: detail for low V_{sense} values



The values of V_{sense1} and V_{sense2} used for the input offset calculations are detailed in *Table 10*.

Table 10. Test conditions for V_{os} voltage calculation

Av (V/V)	V_{sense1} (mV)	V_{sense2} (mV)
20	50	5
25	50	5
50	50	5
100	40	5

5.4 Output voltage drift versus temperature

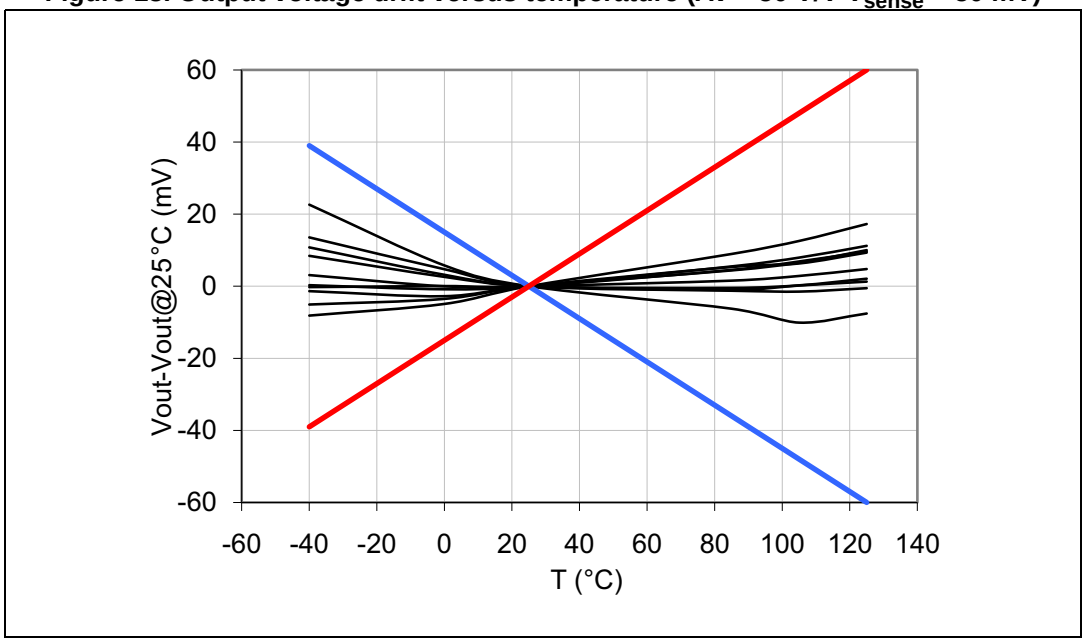
The output voltage drift versus temperature is defined as the maximum variation of V_{out} with respect to its value at 25 °C over the temperature range. It is calculated as follows:

$$\frac{\Delta V_{out}}{\Delta T} = \max \frac{V_{out}(T_{amb}) - V_{out}(25°C)}{T_{amb} - 25°C}$$

with $T_{min} < T_{amb} < T_{max}$.

Figure 18 provides a graphical definition of the output voltage drift versus temperature. On this chart, V_{out} is always within the area defined by the maximum and minimum variation of V_{out} versus T, and T = 25 °C is considered to be the reference.

Figure 18. Output voltage drift versus temperature (Av = 50 V/V V_{sense} = 50 mV)



5.5 Input offset drift versus temperature

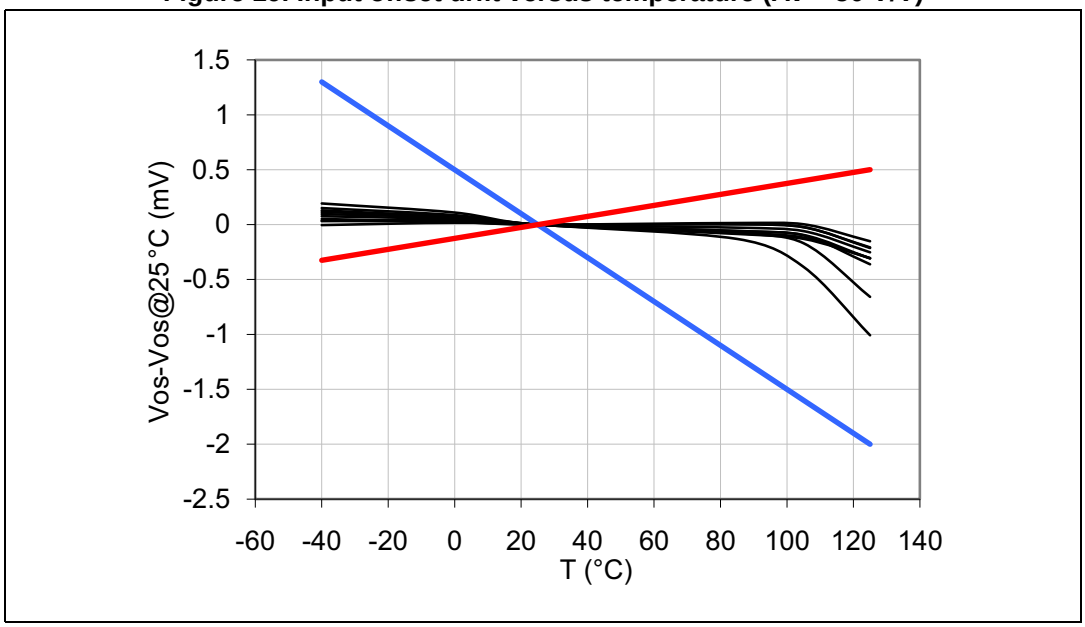
The input voltage drift versus temperature is defined as the maximum variation of V_{os} with respect to its value at 25 °C over the temperature range. It is calculated as follows:

$$\frac{\Delta V_{os}}{\Delta T} = \max \frac{V_{os}(T_{amb}) - V_{os}(25°C)}{T_{amb} - 25°C}$$

with $T_{min} < T_{amb} < T_{max}$.

Figure 19 provides a graphical definition of the input offset drift versus temperature. On this chart, V_{os} is always within the area defined by the maximum and minimum variation of V_{os} versus T, and T = 25 °C is considered to be the reference.

Figure 19. Input offset drift versus temperature (Av = 50 V/V)



5.6 Output voltage accuracy

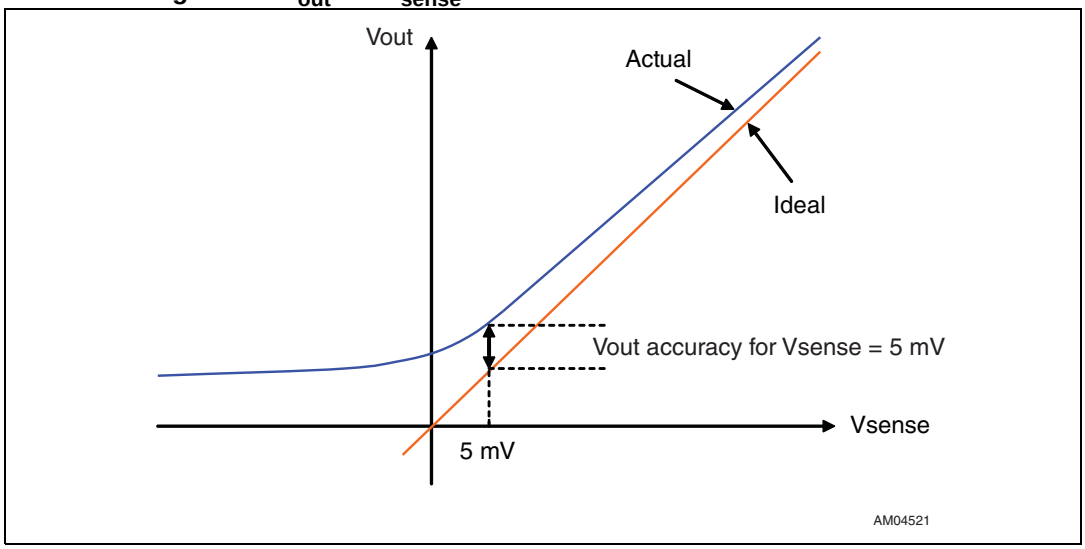
The output voltage accuracy is the difference between the actual output voltage and the theoretical output voltage. Ideally, the current sensing output voltage should be equal to the input differential voltage multiplied by the theoretical gain, as in the following formula.

$$V_{out\text{-}th} = Av.V_{sense}$$

The actual value is very slightly different, mainly due to the effects of:

- the input offset voltage V_{os}
- the non-linearity

Figure 20. V_{out} vs. V_{sense} theoretical and actual characteristics



The output voltage accuracy, expressed as a percentage, can be calculated with the following formula,

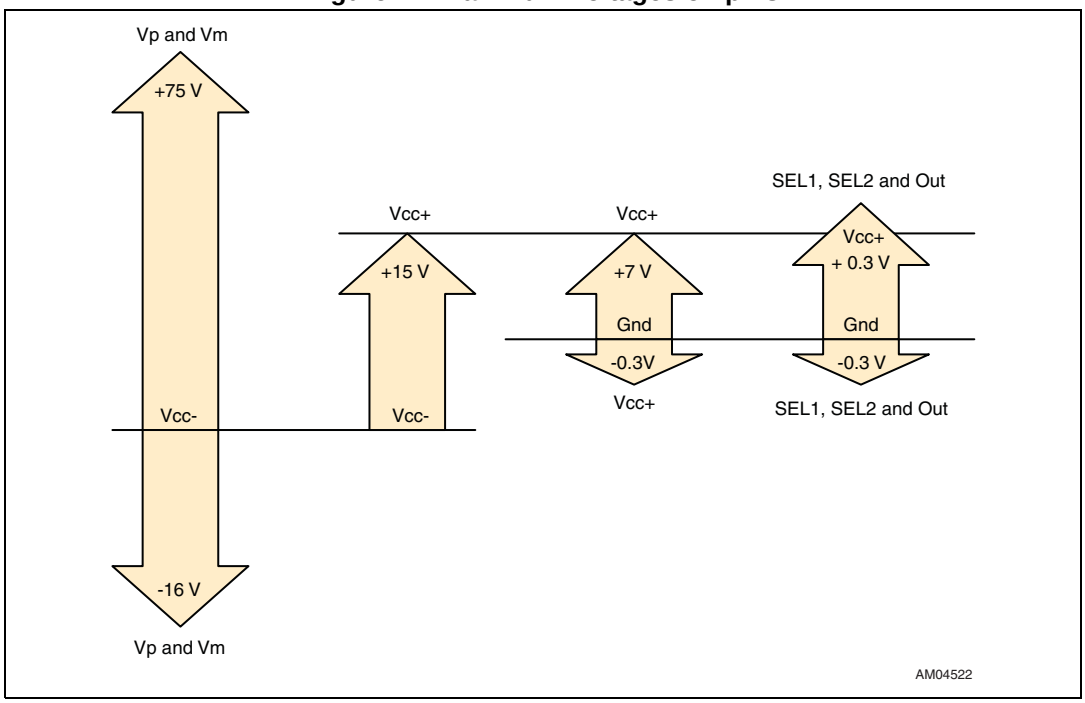
$$\Delta V_{out} = \frac{abs(V_{out} - (Av \cdot V_{sense}))}{Av \cdot V_{sense}}$$

with 20 V/V, 25 V/V, 50 V/V or 100 V/V depending on the configuration of the SEL1 and SEL2 pins.

6 Maximum permissible voltages on pins

The CS70 can be used in either a single or dual supply configuration. The dual-supply configuration is achieved by disconnecting Vcc- and Gnd, and connecting Vcc- to a negative supply. *Figure 21* illustrates how the absolute maximum voltages on input pins Vp and Vm are referred to the V_{CC}- potential, while the maximum voltages on the positive supply pin, gain selection pins, and output pins are referred to the Gnd pin. It should also be noted that the maximum voltage between Vcc- and Vcc+ is limited to 15 V.

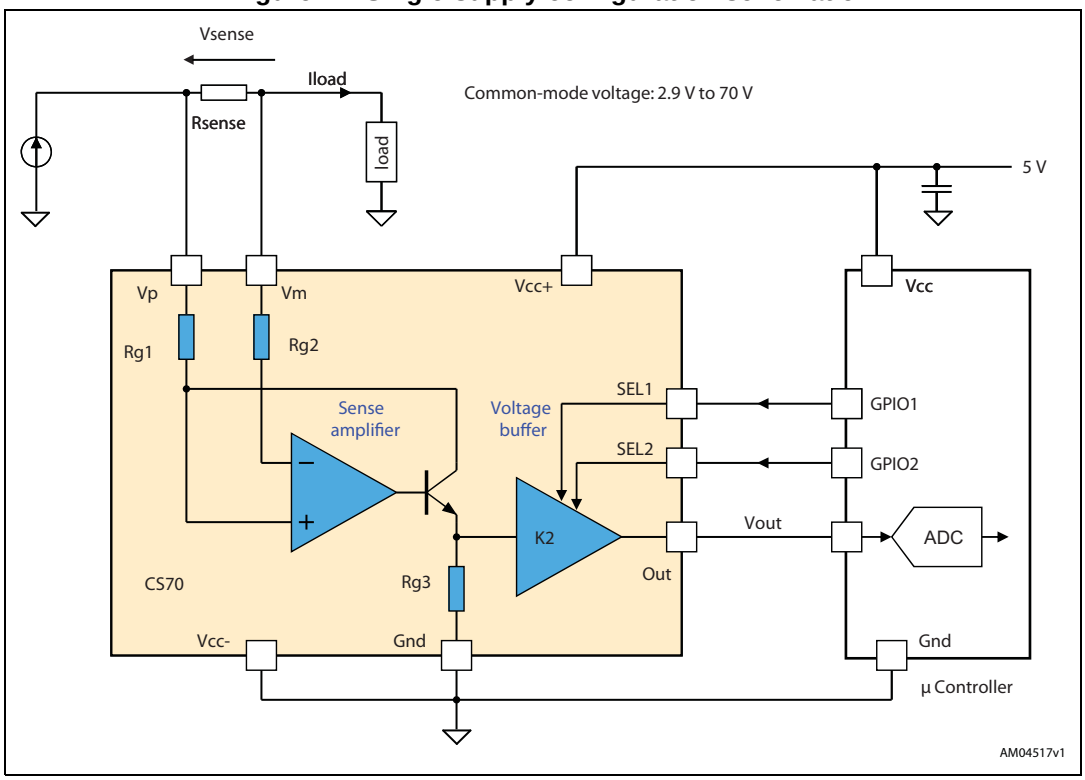
Figure 21. Maximum voltages on pins



7 Application information

The CS70 can be used to measure current and to feed back the information to a microcontroller.

Figure 22. Single-supply configuration schematic



The current from the supply flows to the load through the R_{sense} resistor, causing a voltage drop equal to V_{sense} across R_{sense}. The amplifier's input currents are negligible, therefore its inverting input voltage is equal to Vm. The amplifier's open-loop gain forces its non-inverting input to the same voltage as the inverting input. Consequently, the amplifier adjusts the current flowing through R_{g1} so that the voltage drop across R_{g1} matches V_{sense} exactly.

Therefore, the drop across R_{g1} is:

$$V_{Rg1} = V_{sense} = R_{sense}.I_{load}$$

If I_{Rg1} is the current flowing through R_{g1}, then I_{Rg1} is given by the formula:

$$I_{Rg1} = V_{sense}/R_{g1}$$

The I_{Rg1} current flows entirely into resistor R_{g3} (the input bias current of the buffer is negligible). Therefore, the voltage drop on the R_{g3} resistor can be calculated as follows.

$$V_{Rg3} = R_{g3}.I_{Rg1} = (R_{g3}/R_{g1}).V_{sense= K1}.V_{sense} \text{ with } K1=R_{g3}/R_{g1}.$$

The voltage across the R_{g3} resistor is buffered to the Out pin by the voltage buffer, featuring a gain equal to K2. Therefore V_{out} can be expressed as:

$$V_{out} = K1.K2.V_{sense = Av}.V_{sense \text{ with } Av=} K1.K2$$

or: $V_{out} = {}_{Av}.R_{sense}.I_{load}$

The resistor ratio, K1 = R_{g3}/R_{g1}, is internally set to 20 V/V, and the voltage buffer gain, K2, can be set to 1, 1.25, 2.5, or 5 depending on the voltage applied on the SEL1 and SEL2 pins. Since they define the full-scale output range of the application, the R_{sense} resistor and the amplification gain Av are important parameters and must therefore be selected carefully.

8 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK® packages, depending on their level of environmental compliance. ECOPACK® specifications, grade definitions and product status are available at: *www.st.com*. ECOPACK® is an ST trademark.

8.1 TSSOP8 package information

Figure 23. TSSOP8 package mechanical drawing

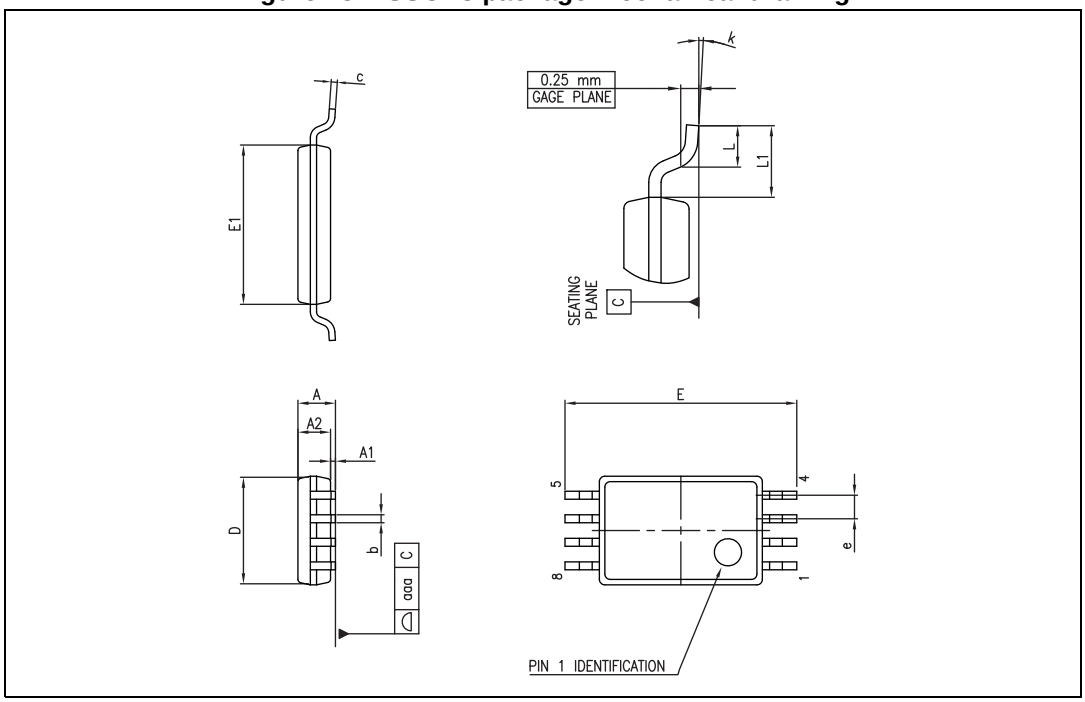


Table 11. TSSOP8 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.20			0.047
A1	0.05		0.15	0.002		0.006
A2	0.80	1.00	1.05	0.031	0.039	0.041
b	0.19		0.30	0.007		0.012
c	0.09		0.20	0.004		0.008
D	2.90	3.00	3.10	0.114	0.118	0.122
E	6.20	6.40	6.60	0.244	0.252	0.260
E1	4.30	4.40	4.50	0.169	0.173	0.177
e		0.65			0.0256	
k	0°		8°	0°		8°
L	0.45	0.60	0.75	0.018	0.024	0.030
L1		1			0.039	
aaa			0.10			0.004

9 Revision history

Table 12. Document revision history

Date	Revision	Changes
06-Mar-2014	1	Initial release.

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