Application Note

NOVOSENSE

Output Pin Over-voltage Protection of NSPASx

AN-12-0002

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ABSTRACT

This application note introduces the typical application circuit of NSPASx series with an over-voltage protection resistor at the output pin. It describes how to calculate the protection resistor value according to different over-voltage protection requirements. In addition, the methodology to evaluate the effect of protection resistor on the sensor accuracy has also been explained in detail. NSPASx stands for NSPAS3, NSPAS3M & NSPAS1 with the same ASIC inside different packages. This note will take NSPAS3 as an example to demonstrate all related results which could be applicable to the other two series.

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1.Introduction

Figure 1 illustrates pin definition of NSPAS3 while the function description of each pin has been summarized in Table 1. Among the 8 pins, VDDHV, VOUT & GND would be used in real application. VDDHV as the power supply pin could withstand over-voltages up to 28V, however, the VOUT pin could only sustain over-voltages up to 5.5V at 5.0V supply voltage. If the voltage at VOUT pin is higher than 5.5V without any protection, the ASIC inside might be damaged. In this application, a protection resistor is highly recommended to be added between the VOUT pin of the pressure sensor and final assembly terminal, which will be discussed in detail in the following sections.

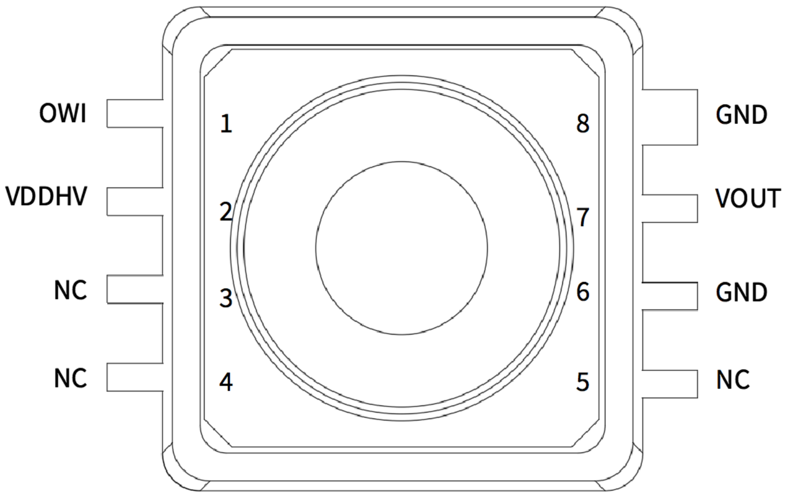

Figure 1. Pin definition (top view)

Pin NO.	Pin name	Description
1	OWI	One-wire interface (leave floating)
2	VDDHV	Power supply with OVP/RVP
3	NC	No connect
4	NC	No connect
5	NC	No connect
6	GND	Ground
7	VOUT	Analog output
8	GND	Ground

Table 1. Pin description

2.Typical application circuit

Figure 2 illustrates the typical application circuit for NSPAS3 which could ensure the basic function of the sensor at most working conditions. If there is an additional EMC requirement, beads and TVSs could be used to improve the system performance. Please refer to the specific EMC application note AN-12-0001 for details. Moreover, the PCB layout of typical application circuit has been shown in Figure 3 which could be taken as reference.

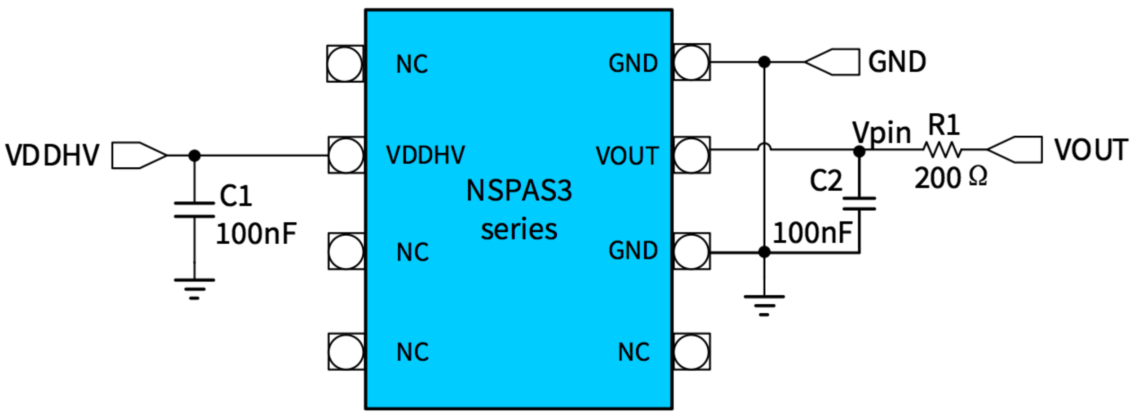

Figure 2. Application circuit

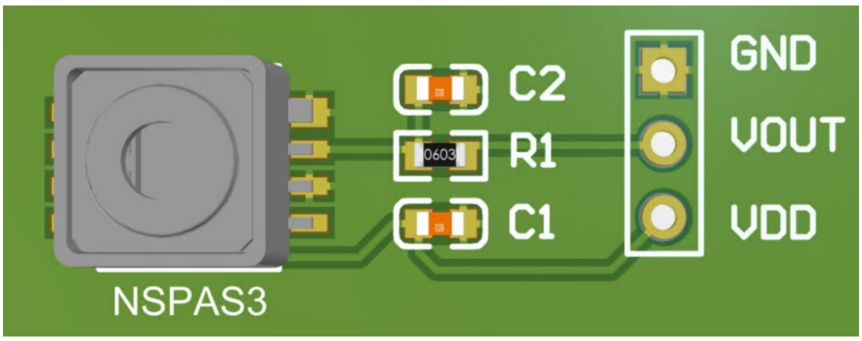

Figure 3. PCB layout of typical application circuit

3.Protection resistor value calculation

For a specific over-voltage applied at the output pin, the minimum protection resistor could be calculated with the following equations:

$$R_{min}=\frac{\Delta U^2}{P_{max}}$$

$$\Delta U=Vout - Vpin_{max}$$

ΔU: voltage drops at the resistor

Vout: over-voltage

$Vpin_{max}$: maximum voltage at the output pin of the sensor (equals 5.5V with 5.0V power supply)

P_{max}: maximum power of the resistor

When the over-voltage is fixed, the protection resistor value is determined by maximum power of the resistor. The larger the power is, the smaller value of the resistor is needed. Furthermore, the maximum current going through the resistor and sinking into the ASIC pin could also be calculated to verify whether this current value exceeds the capability of the ASIC, since the maximum current sinking into the pin should not be larger than 25mA.

$$I_{max}=\frac{P_{max}}{\Delta U}$$

Based on the above equations, the minimum protection resistor & corresponding maximum current could be derived for different over-voltages with fixed resistor power. All the calculation results have been summarized in Table 2 with 2 typical resistor powers, i.e. 100mW for 0603 package and 62.5mW for 0402 package. This lookup table could be used as a reference for resistor quick selection.

No.	Over-voltage /V	R1 Min_Resistor /ohm		R1 Max_Current /mA	
		100mW_0603	62.5mW_0402	100mW_0603	62.5mW_0402
1	10	202.5	324	22.222	13.889
2	11	302.5	484	18.182	11.364
3	12	422.5	676	15.385	9.615
4	13	562.5	900	13.333	8.333
5	14	722.5	1156	11.765	7.353
6	15	902.5	1444	10.526	6.579
7	16	1102.5	1764	9.524	5.952
8	17	1322.5	2116	8.696	5.435
9	18	1562.5	2500	8.000	5.000
10	19	1822.5	2916	7.407	4.630
11	20	2102.5	3364	6.897	4.310
12	21	2402.5	3844	6.452	4.032
13	22	2722.5	4356	6.061	3.788
14	23	3062.5	4900	5.714	3.571
15	24	3422.5	5476	5.405	3.378

Table 2. Protection resistor lookup table

In order to verify the correctness of the calculation results in Table 2, validation test has been conducted with the setup in Figure 4. The sensor was powered by a 5.0V DC power source, while over-voltage was applied on VOUT terminal with one current meter to monitor the sink current and one voltage meter to measure the voltage at VOUT pin (Vpin). For a specific protection resistor, the maximum over-voltage it could bear is determined by its maximum power, which could be converted to the maximum current according to the following equation:

$$P_{max} = I_{max}^2 * R$$

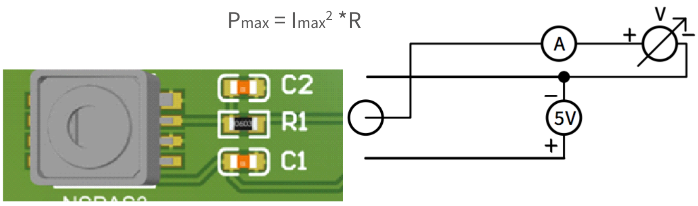

Figure 4. Over-voltage test setup

In the test, 4 different resistors have been tested: i.e. 200ohm, 470ohm, 680ohm & 1000ohm with 0603 package size. For each resistor, the over-voltage starts from 6.0V and increases by 0.5V each step. For each over-voltage, the values of voltage at the output pin and sink current into the output pin have been recorded. The maximum sink current based on calculation was used as the threshold to determine whether the over-voltage could be increased or not. The test result has been summarized in Table 3 which is consistent with the calculation result in Table 2.

No.	Voltage/V	200ohm_0603		470ohm_0603		680ohm_0603		1000ohm_0603	
		Max current 22.36mA		Max current 14.59mA		Max current 12.13mA		Max current 10.00mA	
		Vpin/V	Current/mA	Vpin/V	Current/mA	Vpin/V	Current/mA	Vpin/V	Current/mA
1	6.0	4.25	8.67	4.01	4.22	4.00	2.92	4.00	2.00
2	6.5	4.61	9.37	4.01	5.27	4.00	3.65	4.00	2.50
3	7.0	4.92	10.29	4.02	6.33	4.00	4.38	4.00	2.99
4	7.5	5.17	11.56	4.02	7.38	4.01	5.11	4.00	3.49
5	8.0	5.33	13.21	4.03	8.43	4.01	5.83	4.01	3.99
6	8.5	5.44	15.19	4.46	8.58	4.01	6.56	4.01	4.49
7	9.0	5.48	17.45	4.65	9.23	4.01	7.29	4.01	4.98
8	9.5	5.50	19.83	4.86	9.85	4.02	8.01	4.01	5.48
9	**10.0**	5.50	**22.31**	5.03	10.56	4.29	8.34	4.01	5.98
10	10.5			5.16	11.34	4.53	8.74	4.02	6.48
11	11.0			5.26	12.18	4.70	9.21	4.02	6.98
12	11.5			5.33	13.09	4.87	9.70	4.02	7.48
13	**12.0**			5.39	**14.04**	5.00	10.24	4.02	7.98
14	12.5					5.11	10.81	4.02	8.48
15	13.0					5.20	11.40	4.46	8.54
16	**13.5**					5.28	**12.03**	4.57	8.93
17	14.0							4.69	9.31
18	14.5							4.81	9.70
19	**15.0**							4.91	**10.91**

Table 3. Over-voltage test result

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4.Sensitivity error due to protection resistor

Figure 5 demonstrates the typical application circuit of NSPAS3 at ECU side with one pullup resistor for error detection. In this circuit, the voltage that added to ECU ADC as VOUT_ADC would be higher than Vpin as there is current flows from VDD to Vpin. Therefore, the protection resistor R1 would induce additional sensitivity error. A matrix of 5 different R1 & 6 different R2 and the corresponding sensitivity errors have been listed in Table 4 & 5 for 10% & 90% full scale output respectively.

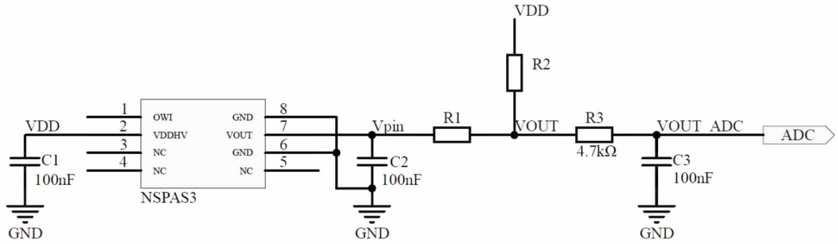

Figure 5. Typical application circuit at ECU side with pullup resistor

Sensitivity error_%F.S. @ VOUT/VDD = 10%						
No.	R2 PullUp resistor/kohm	R1 Output Resistor /kohm				
		0.20	0.47	0.68	0.82	1.00
1	4.7	3.67%	8.18%	11.38%	13.37%	15.79%
2	10	1.76%	4.04%	5.73%	6.82%	8.18%
3	47	0.38%	0.89%	1.28%	1.54%	1.88%
4	100	0.18%	0.42%	0.61%	0.73%	0.89%
5	470	0.04%	0.09%	0.13%	0.16%	0.19%
6	680	0.03%	0.06%	0.09%	0.11%	0.13%

Table 4. Sensitivity error lookup table at VOUT/VDD = 10% (pullup)

Sensitivity error_%F.S. @ VOUT/VDD = 90%						
No.	R2 PullUp resistor/kohm	R1 Output Resistor /kohm				
		0.20	0.47	0.68	0.82	1.00
1	4.7	0.41%	0.91%	1.26%	1.49%	1.75%
2	10	0.20%	0.45%	0.64%	0.76%	0.91%
3	47	0.04%	0.10%	0.14%	0.17%	0.21%
4	100	0.02%	0.05%	0.07%	0.08%	0.10%
5	470	0.00%	0.01%	0.01%	0.02%	0.02%
6	680	0.00%	0.01%	0.01%	0.01%	0.01%

Table 5. Sensitivity error lookup table at VOUT/VDD = 90% (pullup)

Similar to Figure 5, Figure 6 shows the typical application circuit of NSPAS3 at ECU side with one pulldown resistor for error detection. The voltage added to ADC would be smaller than Vpin at the sensor pin. Table 6 & 7 summarize the sensitivity error data as a reference.

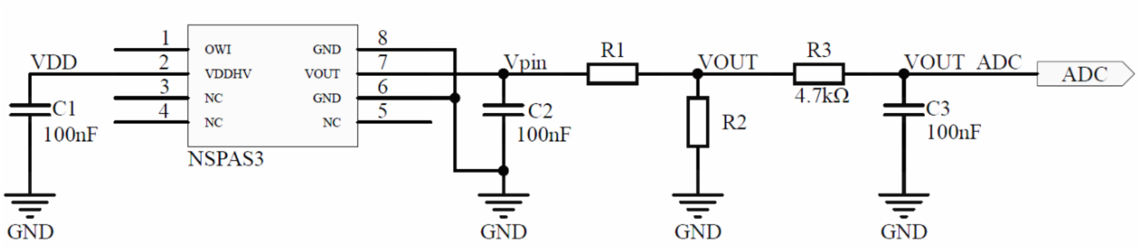

Figure 6. Typical application circuit at ECU side with pulldown resistor

Sensitivity error_%F.S. @ VOUT/VDD = 10%						
No.	R2 PullDown resistor/kohm	R1 Output Resistor /kohm				
		0.20	0.47	0.68	0.82	1.00
1	4.7	-0.41%	-0.91%	-1.26%	-1.49%	-1.75%
2	10	-0.20%	-0.45%	-0.64%	-0.76%	-0.91%
3	47	-0.04%	-0.10%	-0.14%	-0.17%	-0.21%
4	100	-0.02%	-0.05%	-0.07%	-0.08%	-0.10%
5	470	0.00%	-0.01%	-0.01%	-0.02%	-0.02%
6	680	0.00%	-0.01%	-0.01%	-0.01%	-0.01%

Table 6. Sensitivity error lookup table at VOUT/VDD = 10% (pulldown)

Sensitivity error_%F.S. @ VOUT/VDD = 90%						
No.	R2 PullDown resistor/kohm	R1 Output Resistor /kohm				
		0.20	0.47	0.68	0.82	1.00
1	4.7	-3.67%	-8.18%	-11.38%	-13.37%	-15.79%
2	10	-1.76%	-4.04%	-5.73%	-6.82%	-8.18%
3	47	-0.38%	-0.89%	-1.28%	-1.54%	-1.88%
4	100	-0.18%	-0.42%	-0.61%	-0.73%	-0.89%
5	470	-0.04%	-0.09%	-0.13%	-0.16%	-0.19%
6	680	-0.03%	-0.06%	-0.09%	-0.11%	-0.13%

Table 7. Sensitivity error lookup table at VOUT/VDD = 90% (pulldown)

5.Summary

This application note describes the over-voltage protection circuit of NSPASx with one current limitation resistor. The resistor calculation method has been discussed in detail based on different over-voltage requirements and resistor power. In addition, the sensitivity error induced by the protection resistor has been highlighted and should be taken with care in real application. As the typical application circuit shows in Figure 2, on default, one 200 ohm resistor with 0603 package size would be used for over-voltage protection which could withstand 10V max and the pullup or pull down resistor should be larger than 47k ohm to ensure the sensitivity error smaller than 0.5%F.S.

6.Revision History

Revision	Description	Author	Date
1.0	Initial Version.	Charles Chen	2023/08/14

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