PFC sampling Circuit Design Calculations

Project Name：

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Revision History
：

1. **Version：1.0**　　**Date：2015-04-29**　　**Prepared by：wu ping**

   Revision contents：initial vesion；

2. **Version：**　　**Date：**　　**Prepared by：**

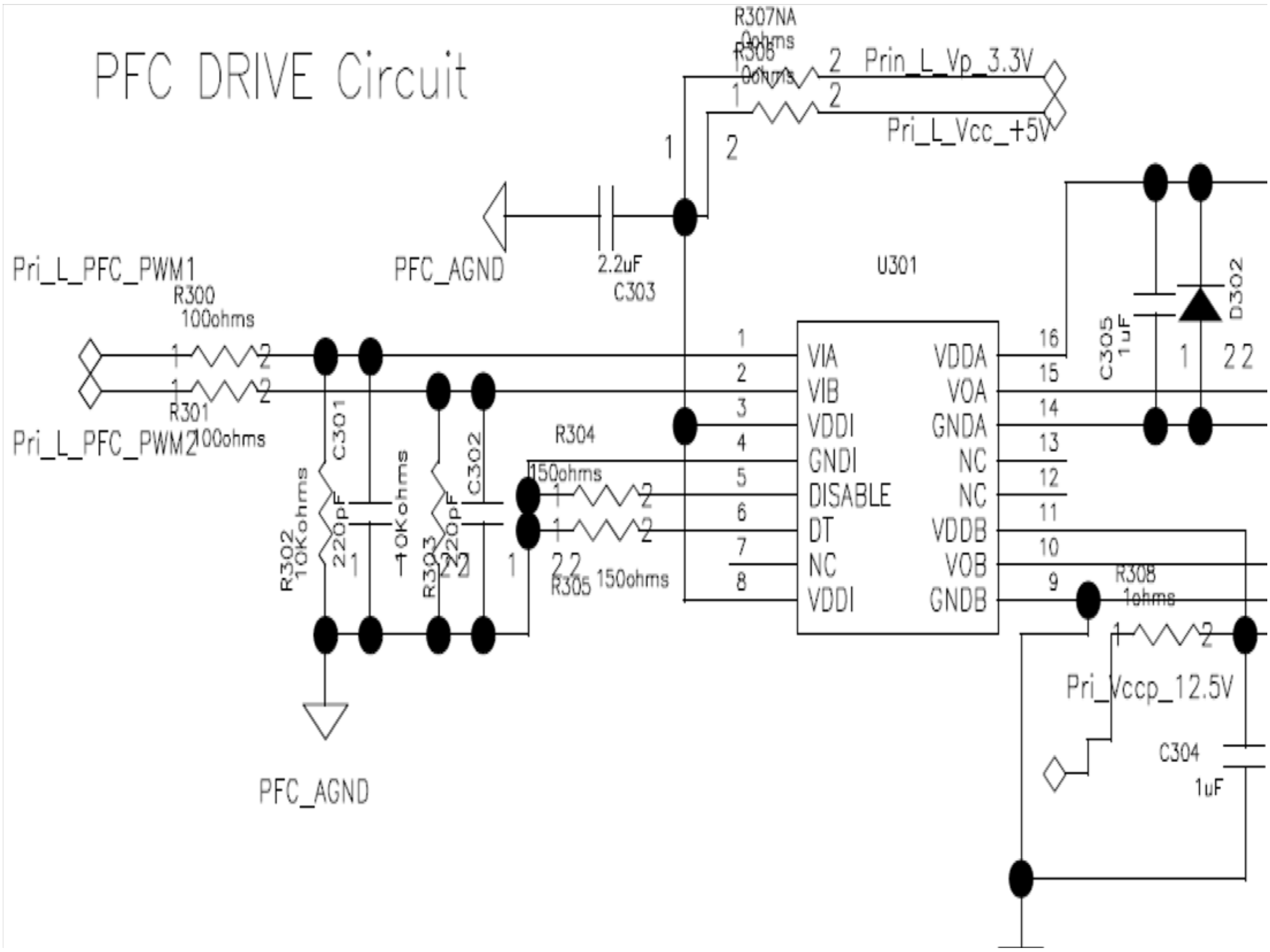
   Revision contents：

1. Design description

This file is used to design the Project

2. Schematic diagrams

PFC_PWM1 is given by DSP,,For the DSP AGND is L line, the upper MOSFET's agnd is after the Lpfc ,the down MOSFET's agnd is Cpfc's agnd, so the voltage between the L line and the MOSFET's agnd is high. So we should choose isoltaed driver.
maximum voltage is 3.3V. To ensure MOSFET reliable switching on, PFCDRV is required higher than 10V. So transistor and its surrounding components are needed..If we drive GaN, the drive voltage should decrese to 7V or less, the negtive voltage is nessary.



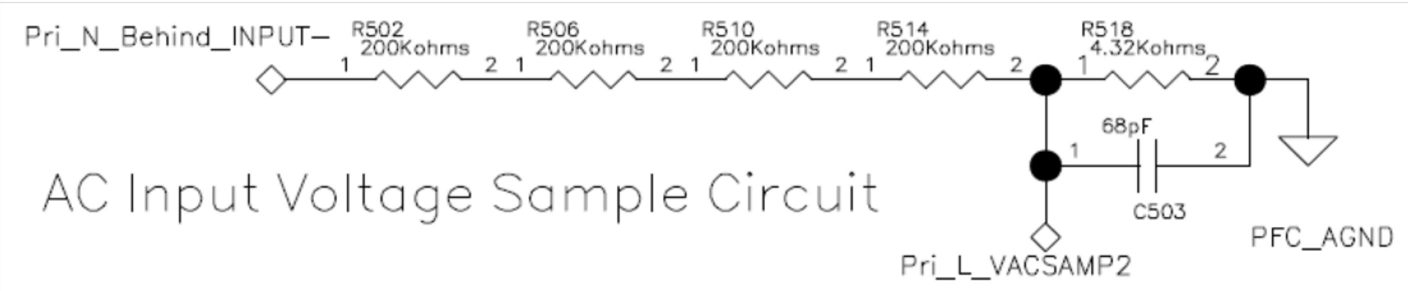
3. Variables

4. Detailed calculations

4.2. PFC Voltage Sample Circuit

4.3 AC Input Voltage Sample Circuit

由于PFC侧的DSP的地在L线软启动电阻前面，所以只需要采样N线，及可知道VAC电压，另外由于N线对于L线也是正负变化的Vac的电压，所以需要在DSP端口处增加偏置电压1.6V左右，才能保证DSP口为正电压



The L line voltage and N line voltage are sampled to ADC of DSP individually.Then the input voltage is calculated by software.
When the surge occur,the ACL line voltage will endure the transient overvoltage.And the highest voltage can be about 1400V.The duration is about tens of μs.

1.R502 R506 R510 R514

07090298 Chip Thick Film Resistor,1/4W,200kohm±1%,1206

$R401 := 200 \cdot 10^{3} \cdot ohm$

$R417 := 4.32 \cdot 10^{3} \cdot ohm$ 07090511 B$Chip Thick Film Resistor,1/8W,4.32kohm±1%,0805,,

When the fault occurs,the highest input voltage is about 415V.

$V_{R401\_pk} := 415V \cdot \sqrt{2} \cdot \frac{R401}{4 \cdot R401 + R417} = 145.937V$ <200V

$$V_{R401\_rms} := \frac{415V}{\sqrt{2}} \cdot \frac{R401}{4 \cdot R401 + R417} = 72.968V$$

$$P_{R401} := \frac{\left(V_{R401\_rms}\right)^2}{R401} = 0.027W$$

<0.6*0.25W

When the surge occur,the transient overvoltage is about 1400V.

$$V_{R401\_OV} := 1400V \cdot \frac{R401}{4 \cdot R401 + R417} = 348.12V$$

<400V

$$I_{R401\_min} := \frac{85V}{4 \cdot R401 + R417} = 0.106 \cdot mA$$

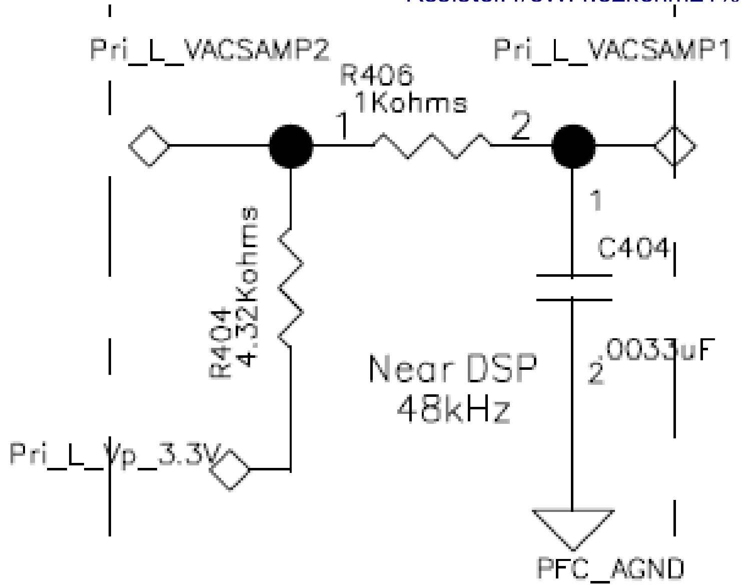
<0.1mA it's not good,Recommendate the current should be higher than 0.1mA for disturbance immune.

2.R416,R417

07090511 B$Chip Thick Film
Resistor 1/8W 4.32kohm±1%,0805,

$$R404 := 4.32 \cdot 10^3 \cdot ohm$$

07090511 B$Chip Thick Film Resistor.1/8W.4.32kohm±1%,0805,



$$V_{R417\_bias} := 3.3V \cdot \frac{R417}{R417 + R404} = 1.65V$$

$$V_{R417\_OV} := \frac{\frac{R417 \cdot R404}{R417+R404}}{4 \cdot R401 + \frac{R417 \cdot R404}{R417 + R404}} \cdot 1400V = 3.77V$$

The transient OV.

$$V_{R417\_max} := V_{R417\_bias} + V_{R417\_OV} = 5.42V$$

<<0.9*150V

$$V_{R417\_pk} := 320V \cdot \sqrt{2} \cdot \frac{\frac{R417 \cdot R404}{R417+R404}}{4 \cdot R401 + \frac{R417 \cdot R404}{R417 + R404}} = 1.219V$$

$V_{R417\_work} := V_{R417\_pk} + V_{R417\_bias}$ $V_{R417\_work} = 2.869V$ <3V is OK

$V_{R417\_work\_neg} := V_{R417\_bias} - V_{R417\_pk}$ $V_{R417\_work\_neg} = 0.431V$ >0V is ok

3.C505

08070701 Chip Multilayer Ceramic Capacitor,100V,68pF,±5%,NPO,0603,0.90mm,350.00,

$C413 := 68 \cdot pF$ 6.628<<0.75*100V

$R417 \cdot C413 = 0.294 \cdot \mu s$

$\frac{1}{2\pi R417 \cdot C413} = 541.786 \cdot kHz$ >>100Hz

4.R404

07090511 B$Chip Thick Film Resistor,1/8W,4.32kohm±1%,0805,

5.42V<<0.9*150V

5.R406,R424

07090980 Chip Thick Film Resistor,1/16W,1KΩ,±1%,0402,,,

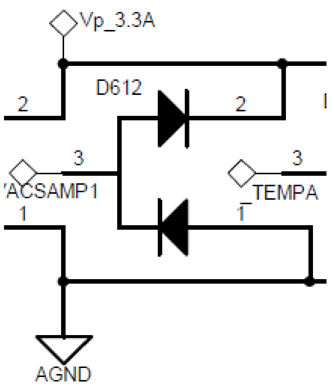
5.42V<<0.9*50V

6.C404,C415

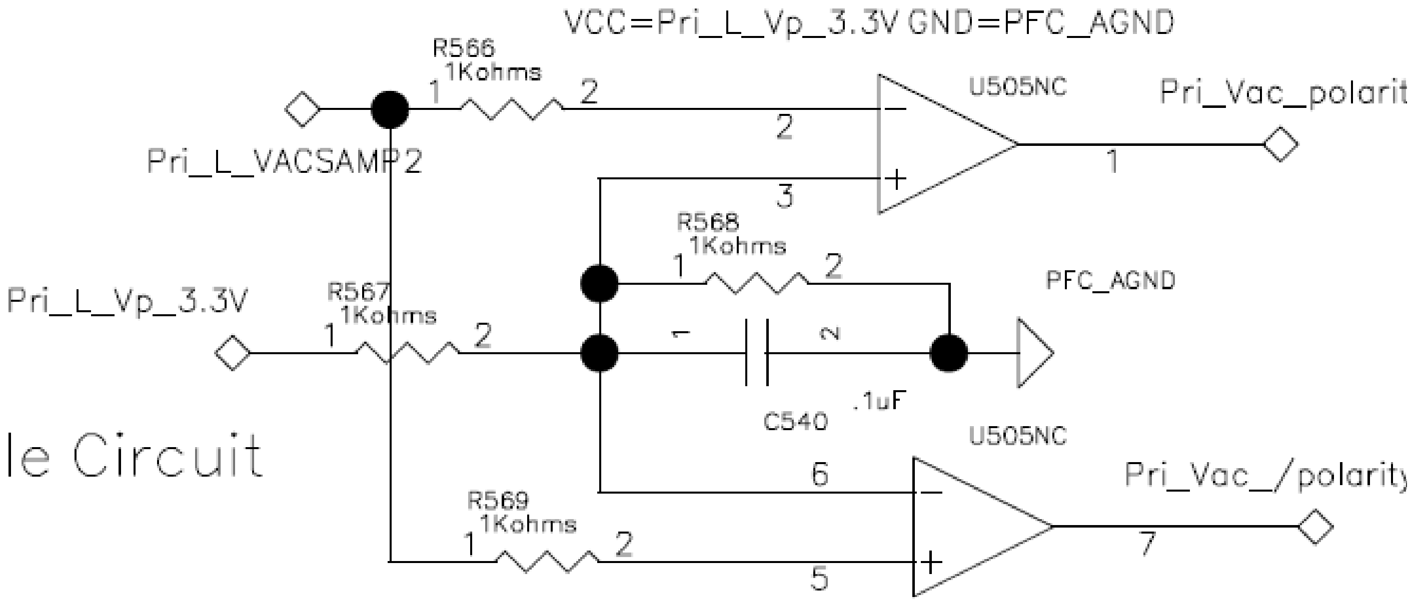
08070595 Chip Multilayer Ceramic Capacitor,100V,3300pF±10%,X7R,0603,0.9mm

5.42V<<0.75*100V

$1000 \cdot ohm \cdot 3.3nF = 3.3 \cdot \mu s$ The RC cannot snub the surge peak voltage.

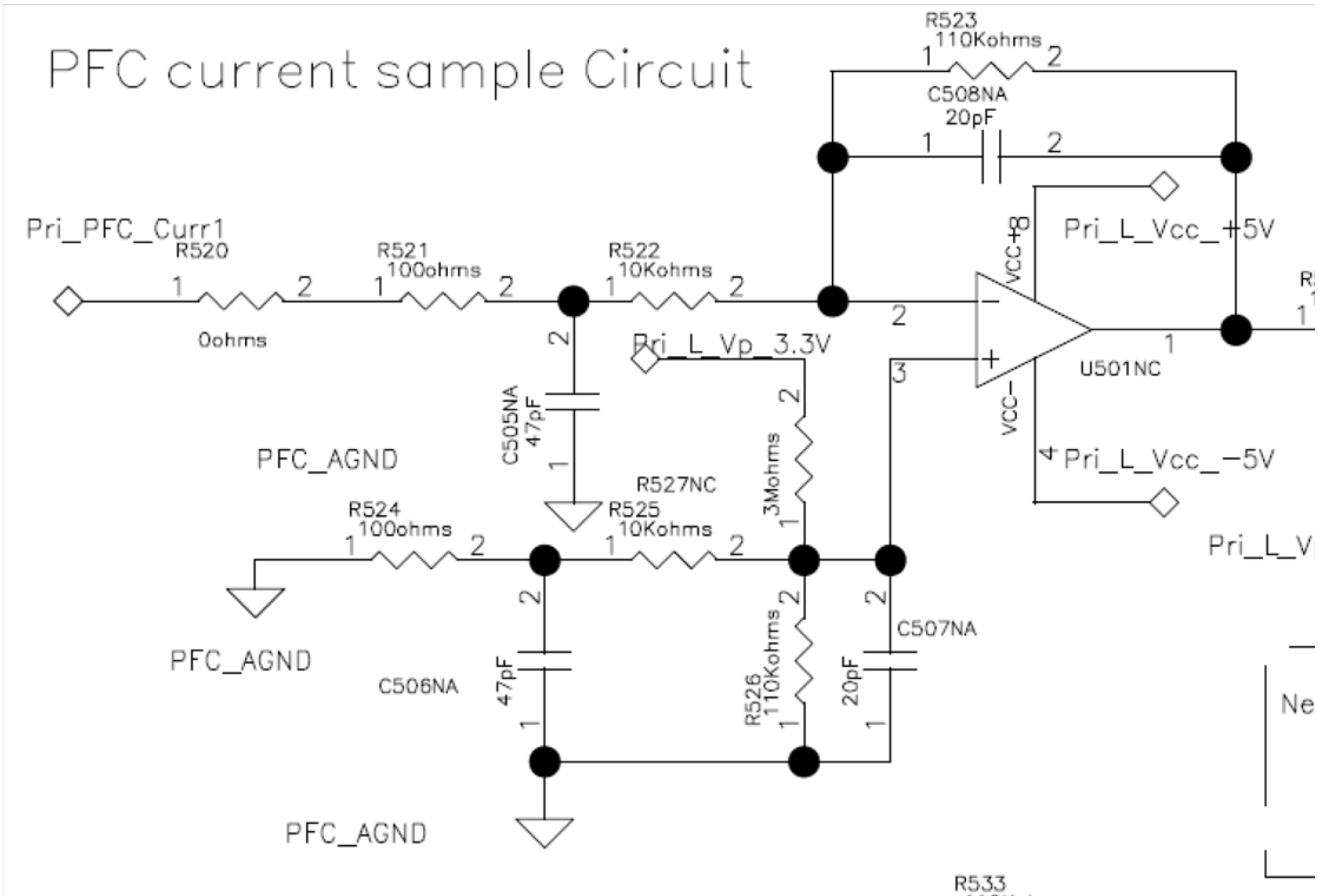


The D612 is used to clamp the OV.



上图电路为AC极性判断电路，用于后面获得正确的负电流比较信号。在正半周工作时，负电流为-2A，在负半周工作时，反抽电流为正电流2A。
输出负电平为有效信号：输入VACSAMP2为N线对L线的信号，且有正的1.65V叠加偏置信号。
VAC+，VACSAMP2为偏负，polarity为高，/polarity为低
VAC-，VACSAMP2为偏正，polarity为低，/polarity为高

4.5 PFC Current sample circuit



R521 := 100Ω   R522 := 11KΩ   R523 := 47KΩ

R538 := 10KΩ   R539 := 10KΩ   C505 := 47pF   C508 := 20pF

Vcc_3V3 := 3.3V   Vcc_5V := 5V

1. U501 AD826

Slew Rate	R_{LOAD} = 1 kΩ	±5 V	200	250		V/μs
	Gain = −1	±15 V	300	350		V/μs
		0, +5 V	150	200		V/μs
Settling Time to 0.1%	−2.5 V to +2.5 V	±5 V		45		ns
	0 V–10 V Step, A_V = −1	±15 V		45		ns
to 0.01%	−2.5 V to +2.5 V	±5 V		70		ns
	0 V–10 V Step, A_V = −1	±15 V		70		ns
Unity Gain Bandwidth		±5 V	30	35		MHz
		±15 V	45	50		MHz
		0, +5 V	25	29		MHz
POWER SUPPLY						
Operating Range	Dual Supply		±2.5		±18	V
	Single Supply		+5		+36	V
Common-Mode Rejection Ratio	V_{CM} = ±2.5 V, T_{MIN}–T_{MAX}	±5 V	80	100		dB
	V_{CM} = ±12 V	±15 V	86	120		dB
	T_{MIN} to T_{MAX}	±15 V	80	100		dB

$Rcurr\_samp := 10 \times 10^{-3}\Omega$ $I\_pk := 30A$ $I\_rms\_max := 9A$ 主功率 计算书

$Ineg := -2A$ 两个管子并联

$K\_curr := \frac{R523}{R521 + R522}$ $K\_curr = 4.234$

$Vipfc\_pk := Rcurr\_samp \cdot K\_curr \cdot I\_pk$ $Vipfc\_pk = 1.27V$

$Vipfc\_rms\_max := Rcurr\_samp \cdot K\_curr \cdot I\_rms\_max$ $Vipfc\_rms\_max = 0.381V$

$Vipfc\_neg := Rcurr\_samp \cdot K\_curr \cdot Ineg$ $Vipfc\_neg = -0.085V$

由于输入信号有正有负，所以需要后面叠加一个偏置电压，然后进入DSP采样

$Vbais := Vcc\_3V3 \cdot \frac{R538}{R538 + R539}$ $Vbais = 1.65V$

$Vpfccurr\_pk := Vipfc\_pk \cdot \frac{R539}{R538 + R539} + Vbais$ $Vpfccurr\_pk = 2.285V$

$$Vpfccurr\_rms\_max := Vipfc\_rms\_max \cdot \frac{R539}{R538 + R539} + Vbais \qquad Vpfccurr\_rms\_max = 1.841V$$

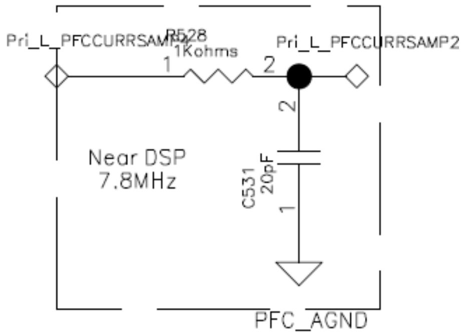
$$Vpfccurr\_neg := Vipfc\_neg \cdot \frac{R539}{R538 + R539} + Vbais \qquad Vpfccurr\_neg = 1.608V$$

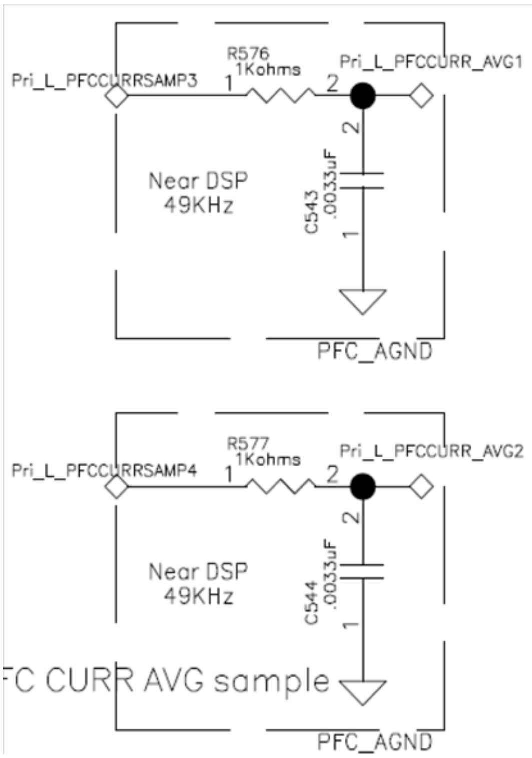
输入正半周时
-2A

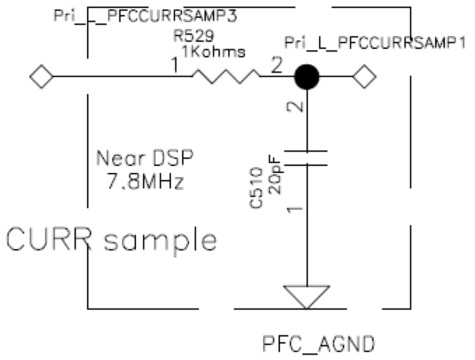
$$Vpfccurr\_pos := -Vipfc\_neg \cdot \frac{R539}{R538 + R539} + Vbais \qquad Vpfccurr\_pos = 1.692V$$

输入负半周时的
+2A

$$\frac{1}{2 \cdot \pi \cdot R523 \cdot C508} = 169.314 \cdot kHz$$







$R528 := 1k\Omega \qquad C531 := 20pF$

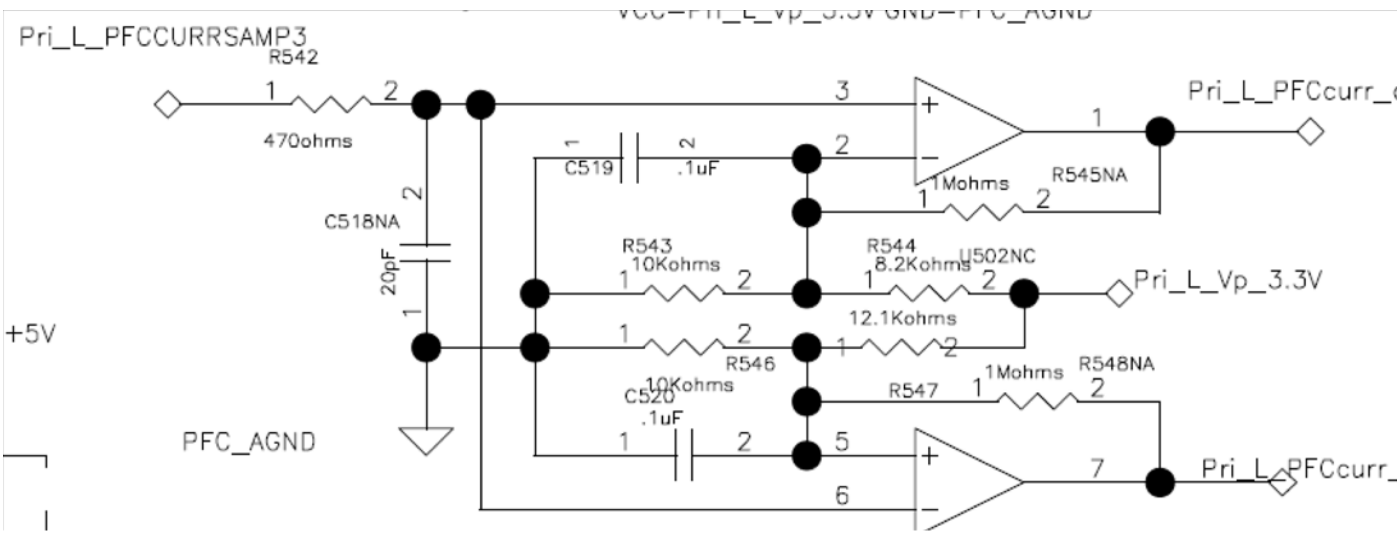
$R576 := 1k\Omega \qquad C543 := 3.3nF$

$$\frac{1}{2 \cdot \pi \cdot R528 \cdot C531} = 7.958 \times 10^{3} \cdot kHz$$

信号PFCCURRsamp1和PFCCURRsamp2用于实时的电流波形采样

$$\frac{1}{2 \cdot \pi \cdot R576 \cdot C543} = 48.229 \cdot kHz$$

信号PFCCURR_AVG1和FCCURR_AVG2用于平均的电流波形采样



$R542 := 470\Omega$ $C518 := 20pF$

$R543 := 10K\Omega$ 07091297 B$Chip Thick Film Resistor,1/16W,10KΩ,±0.1%,0603,

$R544 := 9.53K\Omega$ 07090708 B$Chip Resistor,1,10W,9.53K,±0.1%,0805,

$R546 := 9.53K\Omega$ 07090708 B$Chip Resistor,1,10W,9.53K,±0.1%,0805,

$R547 := 10K\Omega$ 07091297 B$Chip Thick Film Resistor,1/16W,10KΩ,±0.1%,0603,

$R548 := 1M\Omega$ $R545 := R548$

$$\frac{1}{2\cdot\pi\cdot R542\cdot C518} = 1.693\times 10^{4}\cdot kHz$$

$V\_CMP1 := Vcc\_3V3\cdot\frac{R543}{R543+R544}$ $V\_CMP1 = 1.69V$ $Vpfccurr\_pos = 1.692V$ 目标值

$V\_CMP1\_max := Vcc\_3V3\cdot\frac{R543\cdot(1+0.1\%)}{R543\cdot(1+0.1\%)+R544\cdot(1-0.1\%)}$ $V\_CMP1\_max = 1.691V$

$V\_CMP1\_min := Vcc\_3V3\cdot\frac{R543\cdot(1-0.1\%)}{R543\cdot(1-0.1\%)+R544\cdot(1+0.1\%)}$ $V\_CMP1\_min = 1.688V$

$V\_CMP2 := Vcc\_3V3\cdot\frac{R546}{R546+R547}$ $V\_CMP2 = 1.61V$ $Vpfccurr\_neg = 1.608V$ 目标值

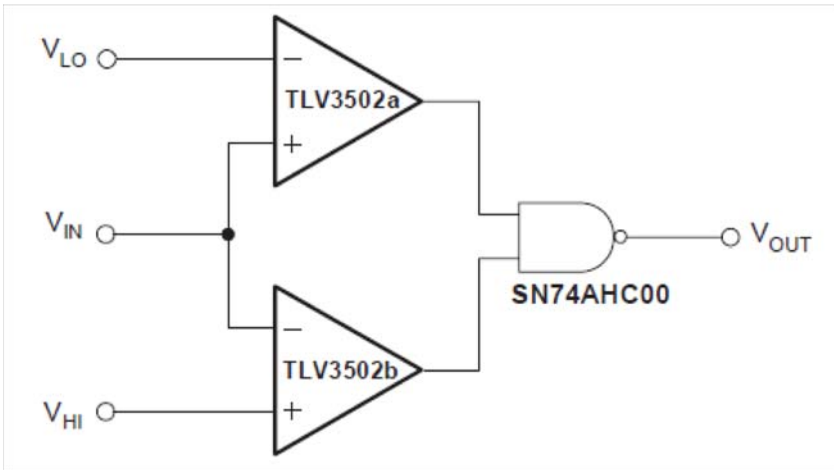
$V\_CMP2\_max := Vcc\_3V3\cdot\frac{R546\cdot(1+0.1\%)}{R546\cdot(1+0.1\%)+R547\cdot(1-0.1\%)}$ $V\_CMP2\_max = 1.612V$

$V\_CMP2\_min := Vcc\_3V3\cdot\frac{R546\cdot(1-0.1\%)}{R546\cdot(1-0.1\%)+R547\cdot(1+0.1\%)}$ $V\_CMP2\_min = 1.609V$

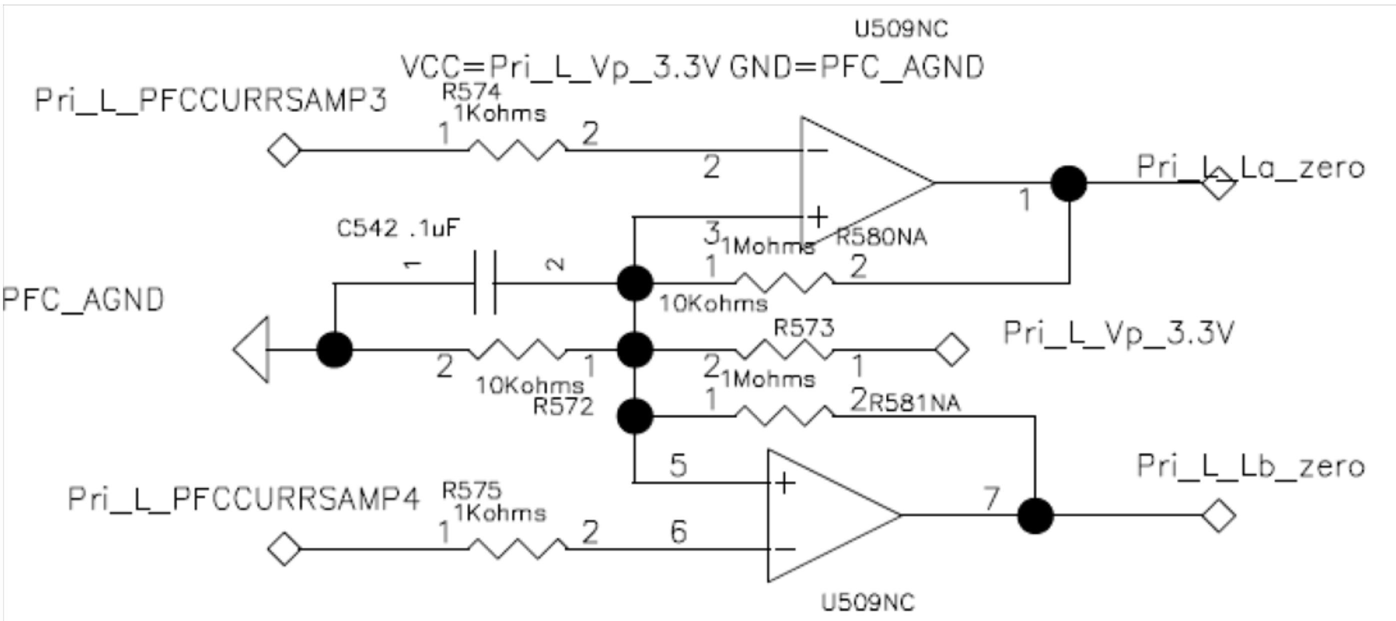
U502 is high speed comparator tlv3502

SWITCHING CHARACTERISTICS						
Propagation Delay Time(3)	$T_{(pd)}$	ΔV_{IN} = 100mV, Overdrive = 20mV		4.5	6.4	ns
		ΔV_{IN} = 100mV, Overdrive = 20mV			**7**	**ns**
		ΔV_{IN} = 100mV, Overdrive = 5mV		7.5	10	ns
		ΔV_{IN} = 100mV, Overdrive = 5mV			**12**	**ns**
Propagation Delay Skew(4)	$\Delta t_{(SKEW)}$	ΔV_{IN} = 100mV, Overdrive = 20mV		0.5		ns
Maximum Toggle Frequency	f_{MAX}	Overdrive = 50mV, V_S = 5V		80		MHz
Rise Time(5)	t_R			1.5		ns
Fall Time(5)	t_F			1.5		ns
POWER SUPPLY						
Specified Voltage	V_S		+2.7		+5.5	V

- **HIGH SPEED: 4.5ns**
- **RAIL-TO-RAIL I/O**
- **SUPPLY VOLTAGE: +2.7V to +5.5V**
- **PUSH-PULL CMOS OUTPUT STAGE**



采用的rail to rail输出，可以直接接DSP，不需要OC门输出那种加上拉电阻，在做电平比较操作时需要增加逻辑门电路

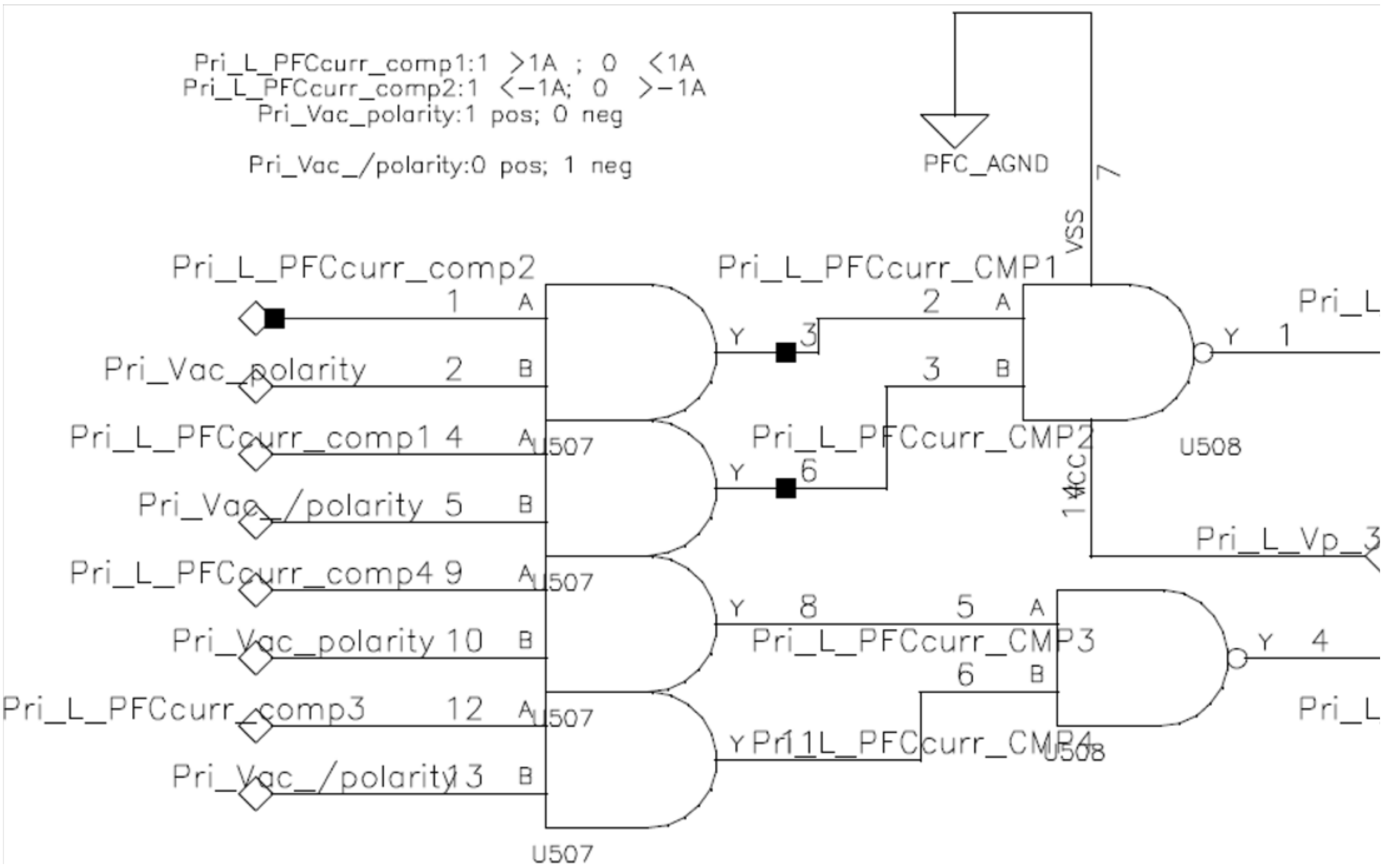


上图是一个电流信号过零采样电路，由于没有判断交流的正半周还是负半周，所以出来的La_zero为方波，且其的占空比在交流正半周时基本小于50%，在交流负半周时基本大于50%.。由于PFCCURRSAMP3为一加了1.65V偏置的电流采样信号，所以比较电平也为1.65V

$R572 := 10k\Omega$ $R573 := 10k\Omega$

$Vc\_zero := Vcc\_3V3\cdot\frac{R572}{R572 + R573}$ $Vc\_zero = 1.65V$

U509采用前面的TLV3501，输出可以直接进入DSP口，且供电为3.3V，与DSP兼容。



U507 36020305 B$CMOS LOGIC,74LVC08,Quad 2-Input AND Gates,TSSOP14,

			SN74LVC08A						UNIT
			T_A = 25°C		–40°C to 85°C		–40°C to 125°C		
			MIN	MAX	MIN	MAX	MIN	MAX	
V_{CC}	Supply voltage	Operating	1.65	3.6	1.65	3.6	1.65	3.6	V
		Data retention only	1.5		1.5		1.5		

PARAMETER	FROM (INPUT)	TO (OUTPUT)	V_{CC}	SN74LVC08A							UNIT
				T_A = 25°C			–40°C to 85°C		–40°C to 125°C		
				MIN	TYP	MAX	MIN	MAX	MIN	MAX	
t_{pd}	A or B	Y	1.8 V ± 0.15 V	1	5	9.3	1	9.8	1	11.3	ns
			2.5 V ± 0.2 V	1	2.9	6.4	1	6.9	1	9	
			2.7 V	1	3	4.6	1	4.8	1	6	
			3.3 V ± 0.3 V	1	2.6	3.9	1	4.1	1	5.5	

U507 为与门，可以3.3V供电，最大延迟为5.5ns

PFCcurr_comp1为1，电流IL1>2A；PFCcurr_comp1为0，电流IL1<2A
PFCcurr_comp2为1，电流IL1<-2A；PFCcurr_comp2为0，电流IL1>-2A

PFCcurr_comp3为1，电流IL2>2A；PFCcurr_comp3为0，电流IL2<2A
PFCcurr_comp4为1，电流IL2<-2A；PFCcurr_comp4为0，电流IL2>-2A

VAC+，VACSAMP2为偏负，polarity为高，/polarity为低
VAC-，VACSAMP2为偏正，polarity为低，/polarity为高

得出的 PFCcurr_CMP1为AC为正半周IL1的时，反抽电流为-2A时的信号，小于-2A为高电平1；
得出的 PFCcurr_CMP2为AC为负半周IL1的时，反抽电流为2A时的信号，大于2A为高电平1；
得出的 PFCcurr_CMP3为AC为正半周IL2的时，反抽电流为-2A时的信号，小于-2A为高电平1；
得出的 PFCcurr_CMP4为AC为负半周IL2的时，反抽电流为2A时的信号，大于2A为高电平1；

U508为或非门，36020303 B$CMOS LOGIC,74LVC02,Quad 2-Input Positive-NOR Gates,TSSOP14,

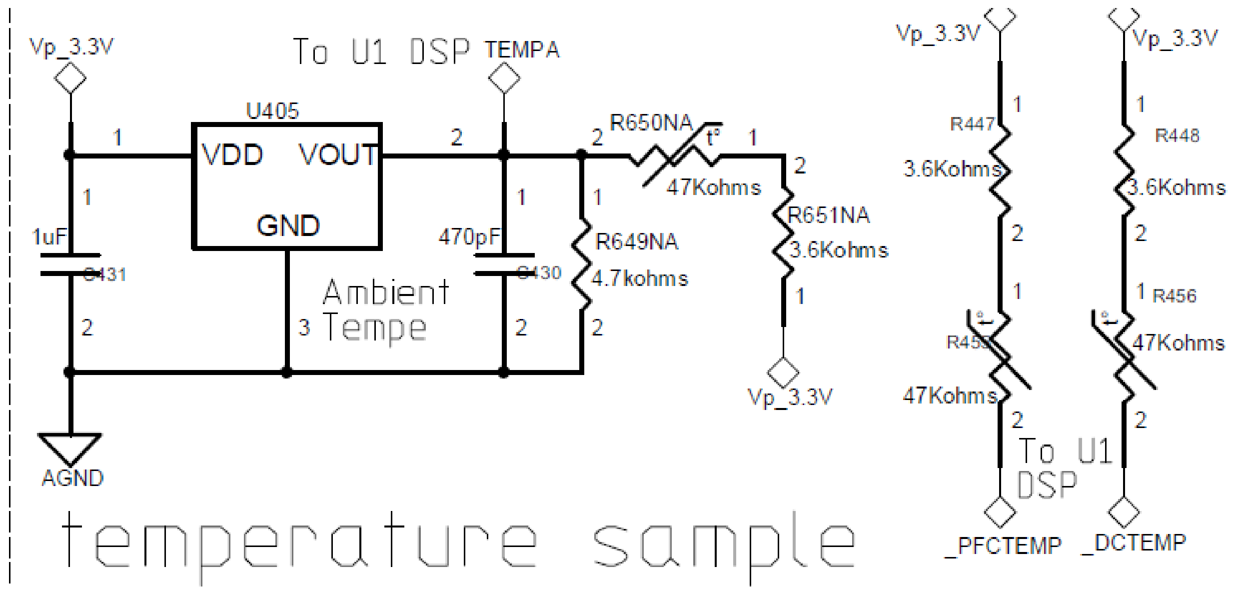
			SN74LVC02A						UNIT
			T_A = 25°C		–40°C to 85°C		–40°C to 125°C		
			MIN	MAX	MIN	MAX	MIN	MAX	
V_{CC}	Supply voltage	Operating	1.65	3.6	1.65	3.6	1.65	3.6	V
		Data retention only	1.5		1.5		1.5		

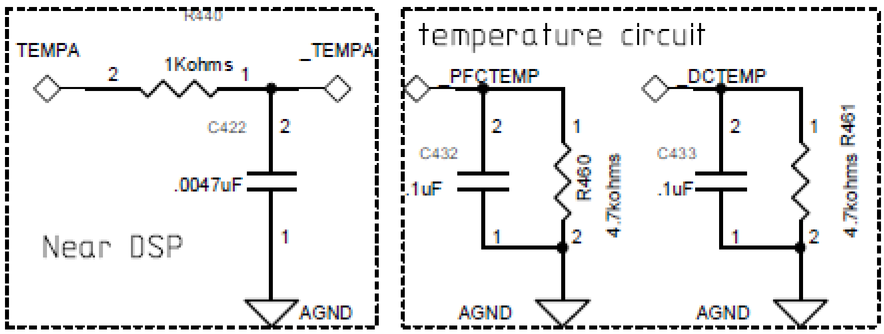
PARAMETER	FROM (INPUT)	TO (OUTPUT)	V_{CC}	SN74LVC02A							UNIT
				T_A = 25°C			–40°C to 85°C		–40°C to 125°C		
				MIN	TYP	MAX	MIN	MAX	MIN	MAX	
t_{pd}	A or B	Y	1.8 V ± 0.15 V	1	3.8	8.4	1	8.9	1	10.4	ns
			2.5 V ± 0.2 V	1	2.9	6.9	1	7.4	1	9.5	
			2.7 V	1	3	5.2	1	5.4	1	7	
			3.3 V ± 0.3 V	1	3.6	4.2	1	4.4	1	5.5	

可用3.3V直接供电，且延迟少，仅为5.5ns

PFCcurr_CMP1和PFCcurr_CMP2 “或非” 以后，得到IL1电流在正负半周的反抽电流的信号Pri_L_PFCcurr_/DSPcmp1，低电有效
PFCcurr_CMP3和PFCcurr_CMP4 “或非” 以后，得到IL1电流在正负半周的反抽电流的信号Pri_L_PFCcurr_/DSPcmp1，低电有效
之所以更改为低电平有效，是因为这个进入DSP的TZ管脚，是低电平有效

4.6 Temperature sample circuit





1. U405 39120014 Temperature Sensor,MCP9700A,Voltage Output,(-40~125℃),10mV/℃,3℃,SOT23-3,3.3V&5V

Parameter	Sym	Min	Typ	Max	Unit	Conditions
Power Supply						
Operating Voltage Range	V_{DD} V_{DD}	2.3 3.1	— —	5.5 5.5	V V	**MCP9700/9700A** **MCP9701/9701A**
Operating Current	I_{DD}	—	6	12	µA	
Power Supply Rejection	$\Delta°C/\Delta V_{DD}$	—	0.1	—	°C/V	
Sensor Accuracy (Notes 1, 2)						
T_A = +25°C	T_{ACY}	—	±1	—	°C	
T_A = 0°C to +70°C	T_{ACY}	-2.0	±1	+2.0	°C	**MCP9700A/9701A**
T_A = -40°C to +125°C	T_{ACY}	-2.0	±1	+4.0	°C	**MCP9700A**

The sensor output can be measured at VOUT. The voltage range over the operating temperature range for the MCP9700/9700A is 100 mV to 1.75V . so it can match the DSP I/O input level

Parameter	Sym	Min	Typ	Max	Unit	Conditions
Typical Load Capacitance	C_{LOAD}	—	—	1000	pF	The MCP9700/9700A and MCP9701/9701A family is characterized and production tested with a capacitive load of 1000 pF.

1. C430 08070251 Chip Multilayer Ceramic Capacitor,50V,470PF±10%,X7R,0603,0.9mm

$C430 := 470pF$

$\text{if}(C430 < 1000pF, \text{"ok"}, \text{"fail"}) = \text{"ok"}$

$V_{C430} := 1.75V$

$\text{if}\left(\frac{V_{C430}}{50V} < 0.75, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$

2. C431 08070656 Chip Multilayer Ceramic Capacitor,16V,1uF±10%,X7R,0603,0.9mm

$V_{C431} := 3.3V$

$\text{if}\left(\frac{V_{C431}}{50V} < 0.75, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$

3. R447 R448 07090628 Chip Thick Film Resistor,1/10W,3.6kohm±1%,0603

$R447 := 3.6k\Omega$

Can be deleted.

4. R460 R461 07090890 Chip Thick Film Resistor,1/10W,4.7kΩ,±1%,0603

$R460 := 35.7k\Omega$

change to 07090530 35.7Kohms

5. R455 R456 07050021 Thermistor,47kohm±5%,NTC,0805

NCP21WB473J03RA

No.	Item	Specification	Condition
2.1	Resistance	47 k ohm ± 5%	at 25°C, zero-power resistance
2.2	B-constant	4050 K± 3%	B-constant is calculated by zero-power resistance of Thermistor in 25°C and 50°C.
2.3	Permissive Operating Current	0.20 mA	at 25°C in still air (*1,*2)
2.4	Rated Electric Power	200 mW	at 25°C in still air (*1,*3)
2.5	Thermal Dissipation Constant	Approx. 2.0 mW/°C	at 25°C in still air (*1)
2.6	Operating temperature Range	-40~+125°C	

$$B = \frac{ln(R_1) - ln(R_2)}{[\,1/T_1 - 1/T_2\,]}$$

$R455\_25 := 47k\Omega$

$B := 4050K$

$T1 := (25 + 273.15)K = 298.15K$

$T2 := (125 + 273.15)K = 398.15K$

$T3 := (-40 + 273.15)K = 233.15K$

$$R455\_125 := R455\_25 \cdot \exp\left[B \cdot \left(\frac{1}{T2} - \frac{1}{T1}\right)\right] = 1.55 \cdot k\Omega$$

$$R455\_n40 := R455\_25 \cdot \exp\left[B \cdot \left(\frac{1}{T3} - \frac{1}{T1}\right)\right] = 2.074 \times 10^{3} \cdot k\Omega$$

$$I_{R455\_max} := \frac{3.3V}{R455\_125 + R460} = 0.089 \cdot mA$$

$$\mathrm{if}\left(\frac{I_{R455\_max}}{0.1mA} < 1, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$$

When R455=R460 the loss on R455 is max.

$$P_{R455\_max} := \frac{(3.3V)^2}{2 \cdot R460} \cdot \frac{1}{2} = 0.076 \cdot mW$$

$$\mathrm{if}\left(\frac{P_{R455\_max}}{200mW} < 0.6, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$$

$$P_{R460\_max} := P_{R455\_max} = 7.626 \times 10^{-5} W$$

$$\mathrm{if}\left(\frac{P_{R460\_max}}{200mW} < 0.6, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$$

6. C432 C433 08070631 Chip Multilayer Ceramic Capacitor,16V,0.1uF±10%,X7R,0402,0.55mm,

$$V_{C432} := 3.3V$$

$$\mathrm{if}\left(\frac{V_{C432}}{16V} < 0.75, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$$

7. R440 07090980 Chip Thick Film Resistor,1/16W,1KΩ,±1%,0402,,,
8. C422 08070250 Chip Multilayer Ceramic Capacitor,50V,4700PF±10%,X7R,0603,0.9mm

$$\frac{1}{2\pi k\Omega \cdot 4.7nF} = 33.863 \cdot kHz$$

$$V_{C422} := 3.3V$$

$$\mathrm{if}\left(\frac{V_{C422}}{50V} < 0.75, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$$

B57620C2473J62

Case Size	Part Number	Zero-Power Resistance (at 25°C)	$B_{25/100}$	$B_{25/85}$	$B_{25/50}$	Chip thickness
0603	B57619C2472* •	4,7 kΩ	3650 K ± 3%	(3635 K)	(3590 K)	0,8 mm
	B57619C2103* •	10 kΩ				0,8 mm
0805	B57620C2472* •	4,7 kΩ	3650 K ± 3%	(3635 K)	(3590 K)	0,8 mm
	B57620C2103* •	10 kΩ				1,2 mm
	B57620C2223* •	22 kΩ	4000 K ± 3%	(3980 K)	(3940 K)	1,2 mm
	B57620C2473* •	47 kΩ				0,8 mm

$B := 4000K$

Two vendor B value is very close.

$$R455\_125 := R455\_25 \cdot \exp\left[B \cdot \left(\frac{1}{T2} - \frac{1}{T1}\right)\right] = 1.617 \cdot k\Omega$$

$$R455\_n40 := R455\_25 \cdot \exp\left[B \cdot \left(\frac{1}{T3} - \frac{1}{T1}\right)\right] = 1.979 \times 10^{3} \cdot k\Omega$$

$$I_{R455\_max} := \frac{3.3V}{R455\_125 + R460} = 0.088 \cdot mA$$

$$\text{if}\left(\frac{I_{R455\_max}}{0.1mA} < 1, \text{"ok"}, \text{"fail"}\right) = \text{"ok"}$$