June 25, 2012

LMP91200

Configurable AFE for Low-Power Chemical Sensing Applications

General Description

The LMP91200 is a configurable sensor AFE for use in low power analytical sensing applications. The LMP91200 is designed for 2-electrode sensors. This device provides all of the functionality needed to detect changes based on a delta voltage at the sensor. Optimized for low-power applications, the LMP91200 works over a voltage range of 1.8V to 5.5V. With its extremely low input bias current it is optimized for use with pH sensors. Also in absence of supply voltage the very low input bias current reduces degradation of the pH probe when connected to the LMP91200. The Common Mode Output pin (VOCM) provides a common mode offset, which can be programmed to different values to accommodate pH sensor output ranges. For applications requiring a high impedance common mode this option is also available. Two guard pins provide support for high parasitic impedance wiring. Support for an external Pt1000, Pt100, or similar temperature sensor is integrated in the LMP91200. The control of this feature is available through the SPI interface. Additionally, a user controlled sensor diagnostic test is available. This function tests the sensor for proper connection and functionality. Depending on the configuration, total current consumption for the device is 50μA while measuring pH. Available in a 16-pin TSSOP package, the LMP91200 operates from -40°C to +125°C.

Key Specifications

Unless otherwise noted, typical values at T_A = 25°C, V_S=(VDD-GND) = 3.3V.

- pH Buffer Input bias current (0<V_{INP} <3.3V)
  - — max @ 25°C ±125 fA
  - — max @ 85°C ±445 fA
- pH Buffer Input bias current (-500mV<V_{INP}-V_{CM} <500mV), V_S=(VDD-GND)=0V
  - — max @ 25°C ±600 fA
  - — max @ 85°C ±6.5 pA
- pH Buffer Input offset voltage ±200 μV
- pH Buffer Input offset voltage drift ±2.5 μV/°C
- Supply current (pH mode) 50 μA
- Supply voltage 1.8 V to 5.5 V
- Operating temperature range -40°C to 125°C
- Package 16-Pin TSSOP

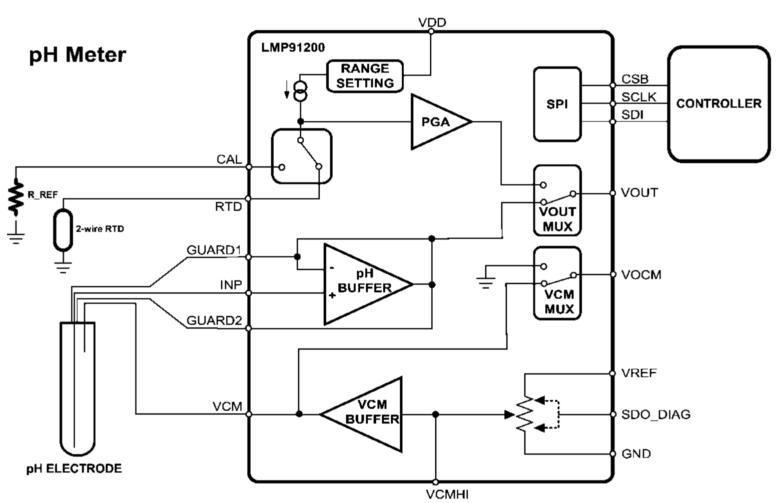
Features

- Programmable output current in temperature measurement
- Programmable Output common mode voltage
- Active guarding
- On board sensor test
- Supported by Webench Sensor AFE Designer
- Supported by Webench Sensor Designer Tools

Applications

- pH sensor platforms

Typical Application



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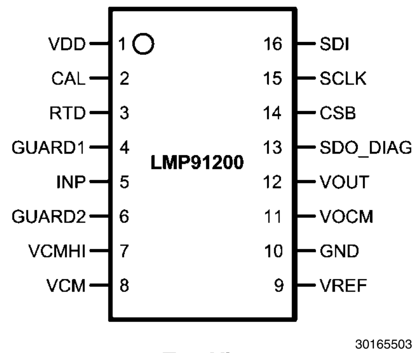
Ordering Information

Package	Part Number	Package Marking	Transport Media	NSC Drawing
16-Pin TSSOP	LMP91200MT	LMP91200MT	95 Units/Rail	MTC16
	LMP91200MTX		2.5k Units Tape and Reel	

Connection Diagram

16-Pin TSSOP



Top View

Pin Descriptions

Pin	Name	Description
1	VDD	Positive Power Supply
2	CAL	Connect an external precision resistor here for purpose of temperature measurement calibration
3	RTD	Pt100/Pt1000 input / internal current source output
4	GUARD1	Active guard pin
5	INP	Non-inverting analog input of pH buffer
6	GUARD2	Active guard pin
7	VCMHI	High Impedance Programmable Common Mode output
8	VCM	Buffered Programmable Common Mode output
9	VREF	Voltage reference input
10	GND	Analog ground
11	VOCM	Output common mode voltage
12	VOUT	Analog Output
13	SDO_DIAG	Serial Data Out /Diagnostic enable
14	CSB	Chip select, low active.
15	SCLK	Serial Clock
16	SDI	Serial Data In

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

ESD Tolerance (Note 2)	
Human Body Model	2000V
Machine Model	150V
Charge Device Model	1000V
Supply Voltage (V_S = VDD-GND)	-0.3V to 6.0V
Voltage between any two pins	-0.3V to VDD+0.3V
Current out at any pin	5mA
Storage Temperature Range	-65°C to 150°C
Junction Temperature (Note 3)	+150°C

For soldering specifications:
see product folder at www.ti.com and www.ti.com/lit/an/snoa549c/snoa549c.pdf

Operating Ratings (Note 1)

Supply Voltage (V_S=VDD-GND)	1.8V to 5.5V
Temperature Range	-40°C to 125°C
Package Thermal Resistance (θ_{JA}(Note 3))	
16-Pin TSSOP	31°C/W

Electrical Characteristics (Note 4)

Unless otherwise specified, all limits guaranteed for T_A = 25°C. V_S=(VDD-GND)=3.3V. VREF=3.3V. Boldface limits apply at the temperature extremes.

Symbol	Parameter	Condition	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
Power supply						
Is	Supply Current (Note 7, Note 16)	pH measurement mode		50	54 **59**	µA
		Temperature measurement mode, I_{CS}=100uA		300	325 **330**	
		Temperature measurement mode, I_{CS}=200uA		400	432 **437**	
		Temperature measurement mode, I_{CS}=1000uA		350	364 **372**	
		Temperature measurement mode, I_{CS}=2000uA		470	477 **477**	
pH Buffer						
Aol_{pH}	Open loop Gain	INP=1.65V 300mV=VOUT=VDD-300mV;	**90**	120		dB
Vos_{pH}	Input Voltage Offset (Note 7)	INP=1/8VREF	-200 **-350**		200 **350**	µV
		INP=7/8VREF	-200 **-350**		200 **350**	
$TcVos_{pH}$	Input offset voltage drift (Note 8, Note 14)	INP=1/8VREF	-2.5		2.5	uV/°C
		INP=7/8VREF	-2.5		2.5	
VOS_{pH_drift}	Long term V_{OSpH} drift (Note 9)	500 hours OPL		150		µV
Ib_{pH}	Input bias current at INP (Note 14)	0V<INP<3.3V	-125		125	fA
		0V<INP<3.3V, 85°C	-445		445	fA
		0V<INP<3.3V, 125°C	-1.5		1.5	pA
		-500mV<(INP-VCM)<500mV, V_S=0V.	-600		600	fA
		-500mV<(INP-VCM)<500mV, 85°C, V_S=0V.	-6.5		6.5	pA
		-500mV<(INP-VCM)<500mV, 125°C, V_S=0V.	-100		100	pA
$GBWP_{pH}$	Gain Bandwidth Product (Note 14)	C_L=10pF, R_L=1Mohm		220		KHz
$CMRR_{pH}$	DC_Common mode rejection ratio	1/8VREF<INP<7/8VREF	80			dB

Symbol	Parameter	Condition	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
$PSRR_{pH}$	DC_Power supply rejection ratio	1.8V<VDD<5V INP=1/8VREF	80			dB
		1.8V<VDD<5V INP=7/8VREF	80			
En_RMS_{pH}	Input referred noise (low frequency) (Note 14)	Integrated 0.1Hz to 10Hz		2.6		μV_{PP}
en_{pH}	Input referred noise (high frequency) (Note 14)	f=1kHz		90		$nV/\sqrt{Hz}$
Isc_{pH}	Output short circuit current (Note 19)	Sourcing, Vout to GND INP=1.65V	**10**	13		mA
		Sinking, Vout to VDD INP=1.65V	**8**	12		mA
VCM Buffer						
VCMHI_acc	VCMHI accuracy		-1.6		1.6	mV
Tc_VCMHI	VCMHI temperature coefficient (Note 10, Note 14)	-40°C<T_A<125°C	-18	-5	8	μV/°C
VCMHI_acc_ VREF	VCMHI_acc vs. VREF (Note 11, Note 14)	1.8V<VREF<5.0V	-500	-100	300	μV/V
$Rout_{VCMHI}$	VCMHI Output Impedance (Note 14)	VCMHI=1/2 VREF		250		KΩ
Aol_{VCM}	Open loop Gain (Note 7)	VCMHI=1/2 VREF, 300mV<VCM<VDD-300mV;	**90**	120		dB
Vos_{VCM}	(VCM-VCMHI) (Note 7)	VCMHI=1/8 VREF	-200 **-350**		200 **350**	μV
		VCMHI=7/8 VREF	-200 **-350**		200 **350**	
$TcVos_{VCM}$	Input offset voltage drif ot (VCM-VCMHI) (Note 8, Note 14)	VCMHI=1/8 VREF	-2.5		2.5	μV/°C
		VCMHI=7/8 VREF	-2.5		2.5	
$Zout_{VCM}$	Output Impedance (Note 14)	f=1KHz		4		Ω
$PSRR_{VCM}$	DC_Power supply rejection ratio	1.8V<VDD<5V, VCMHI=1/8VREF	80			dB
		1.8V<VDD<5V, VCMHI=7/8VREF	80			
En_RMS_{VCM}	Input referred noise (low frequency) (Note 14)	Integrated 0.1Hz to 10Hz		2.6		μV_{PP}
en_{VCM}	Input referred noise (high frequency) (Note 14)	f=1KHz		90		$nV/\sqrt{Hz}$
Isc_{VCM}	Output short circuit current (Note 19)	Sourcing, Vout to GND VCMHI=1/2VREF	**10**	16		mA
		Sinking, Vout to VDD VCMHI=1/2VREF	**8**	12		
Current Source						
I_{CS}	Current Source I_{CAL}, I_{RTD}	Programmable current		100 200 1000 2000		μA

Symbol	Parameter	Condition	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
In_RMS_{CS}	Input referred noise (low frequency) (Note 14)	Integrated 0.1Hz to 10Hz		33		nA_{PP}
in_{CS}	Input referred noise (high frequency) (Note 14)	f=1KHz		120		$pA/\sqrt{Hz}$
TcI_{CS}	Current Source drift(Note 12) (Note 14)		-200	±35	200	ppm/°C
I_acc_{CS}	Current Source accuracy		**-2.5**	1	**2.5**	%
PGA						
Vos_{PGA}	Input Voltage Offset (Note 7)	+IN_PGA (Internal node) = 500mV	-275 **-480**		275 **480**	µV
$TcVos_{PGA}$	Input offset voltage drift (Note 8, Note 14)	+IN_PGA (Internal node) = 500mV	-2.5		2.5	uV/°C
Aol_{PGA}	Open loop Gain	+IN_PGA (Internal node) = 500mV	**90**	120		dB
Av_{PGA}	Gain	Programmable gain		5 10		V/V
Av_acc_{PGA}	Gain accuracy		**-1.3**		**1.3**	%
En_RMS_{PGA}	Input referred noise (low frequency) (Note 14)	Integrated 0.1Hz to 10Hz		2.6		μV_{PP}
en_{PGA}	Input referred noise (high frequency) (Note 14)	f=1KHz		90		$nV/\sqrt{Hz}$
$PSRR_{PGA}$	DC_Power supply rejection ratio	1.8V<VDD<5V, +IN_PGA (Internal node) = 500mV	80			dB
Isc_{PGA}	Output short circuit current (Note 19)	Sourcing, Vout to GND +IN_PGA (Internal node) = 500mV	**10**	16		mA
		Sinking, Vout to VDD +IN_PGA (Internal node) = 500mV	**8**	12		
Reference Input						
Rin_{VREF}	Input impedance (Note 14)			500		KΩ

Electrical Characteristics (Serial Interface) (Note 4)

Unless otherwise specified. All limits guaranteed for T_A=25°C, V_S=(VDD-GND)=3.3V.

Symbol	Parameter	Condition	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
VIL	Logic Low Threshold				0.3XVDD	V
VIH	Logic High Threshold (SDO pin)		0.7XVDD			V
VOL	Output Logic LOW Threshold (SDO pin)	ISDO=100µA			0.2	V
		ISDO=2mA			0.4	
VOH	Output Logic High Threshold	ISDO=100µA	VDD-0.2			V
		ISDO=2mA	VDD-04			
t1	High Period, SCLK	(Note 15)	100			ns
t2	Low Period, SCLK	(Note 15)	100			ns
t3	Set Up Time, CSB to SCLK	(Note 15)	50			ns
t4	Set Up Time, SDI to SCLK	(Note 15)	30			ns
t5	Hold Time,S CLK to SDI	(Note 15)	10			ns
t6	Hold Time,SCLK to SDO_DIAG	(Note 15)	40			ns

Symbol	Parameter	Condition	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
t7	Hold Time, SCLK Transition to CSB Rising Edge	(Note 15)	50			ns
t8	CSB Inactive	(Note 15)	50			ns
t9	Hold Time, SCLK Transition to CSB Falling Edge	(Note 15)	10			ns
t_R/t_F	SDO_DIAG Signal Rise and Fall Times	Diagnostic disabled (Note 14, Note 15)		30		ns

Electrical Characteristics (Diagnostic) (Note 4)

Unless otherwise specified. All limits guaranteed for T_A=25°C, V_S=(VDD-GND)=3.3V.

Symbol	Parameter	Condition	Min (Note 6)	Typ (Note 5)	Max (Note 6)	Units
$DIAG\_t_{SET}$	SDO_DIAG setup time (Note 14)			200		ns
$DIAG\_t_R$/ $DIAG\_t_F$	Diagnostic Rise and Fall Times (Signal at SDO_DIAG pin, in Diagnostic Mode) (Note 14)			30		ns
$DIAG\_t_{ON}$	Minimum t_{ON} of the diagnostic pulse at SDO_DIAG pin in Diagnostic Mode (Note 14)			100		ns
VCM_DIAG_{POS}	Positve Diagnostic pulse amplitude (Note 14)	Base pulse = VCM; High level pulse = VCM+5%VREF		165		mV
VCM_DIAG_{NEG}	Negative Diagnostic pulse amplitude (Note 14)	Base pulse = VCM; High level pulse = VCM-5%VREF		165		mV
VCM_DIAG_acc	Diagnostics Pulse accuracy (Note 14)			0.1		%
$VCM\_DIAG_{t_R}$	Diagnostics Pulse rise time (Note 14)	10% to 90% C=15pF		10		us
$VCM\_DIAG_{t_F}$	Diagnostics Pulse fall time (Note 14)	90% to 10% C=15pF		10		us

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics Tables.

Note 2: Human Body Model, applicable std. MIL-STD-883, Method 3015.7. Machine Model, applicable std. JESD22-A115-A (ESD MM std. of JEDEC) Field-Induced Charge-Device Model, applicable std. JESD22-C101-C (ESD FICDM std. of JEDEC).

Note 3: The maximum power dissipation is a function of $T_{J(MAX)}$, θ_{JA}. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(MAX)} - T_A)/\theta_{JA}$. All numbers apply for packages soldered directly onto a PC Board.

Note 4: Electrical Table values apply only for factory testing conditions at the temperature indicated. Factory testing conditions result in very limited self-heating of the device such that TJ = TA. No guarantee of parametric performance is indicated in the electrical tables under conditions of internal self-heating where TJ >TA.

Note 5: Typical values represent the most likely parametric norm as determined at the time of characterization. Actual typical values may vary over time and will also depend on the application and configuration. The typical values are not tested and are not guaranteed on shipped production material.

Note 6: Limits are 100% production tested at 25°C. Limits over the operating temperature range are guaranteed through correlations using the Statistical Quality Control (SQC) method.

Note 7: Boldface limits are production tested at 125°C. Limits are guaranteed through correlations using the Statistical Quality Control (SQC) method.

Note 8: Offset voltage average drift is determined by dividing the change in V_{OS} at the temperature extremes by the total temperature change.

Note 9: Offset voltage long term drift is determined by dividing the change in V_{OS} at time extremes of OPL procedure by the length of the OPL procedure. OPL procedure: 500 hours at 150°C are equivalent to about 15 years.

Note 10: VCMHI voltage average drift is determined by dividing the change in VCMHI at the temperature extremes by the total temperature change.

Note 11: VCMHI_acc vs. VREF is determined by dividing the change in VCMHI_acc at the VREF extremes by the total VREF change.

Note 12: Current source drift is determined by dividing the change in I_{CS} at the temperature extremes by the total temperature change.

Note 13: Positive current corresponds to current flowing into the device.

Note 14: This parameter is guaranteed by design and/or characterization and is not tested in production.

Note 15: Load for these tests is shown in the timing diagram test circuit.

Note 16: Excluding all currents which flows out from the device.

Note 17: The short circuit test is a momentary open loop test.

Note 18: The voltage on any pin should not exceed 6V relative to any other pins.

Note 19: Short circuit test is a momentary test.

Test Circuit Diagrams

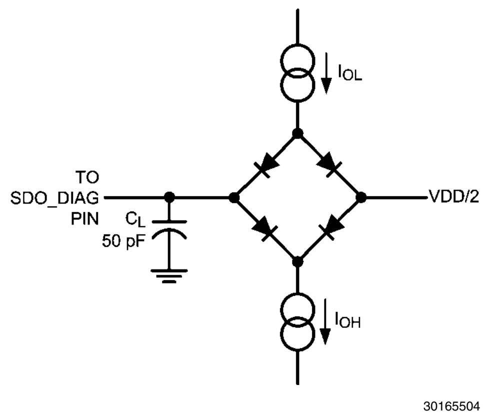


FIGURE 1.

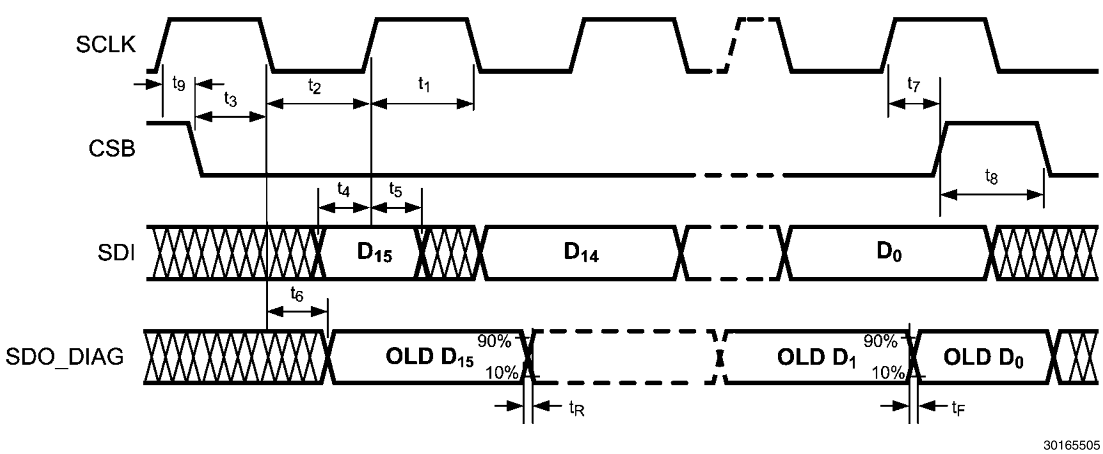


FIGURE 2. SERIAL INTERFACE TIMING DIAGRAM

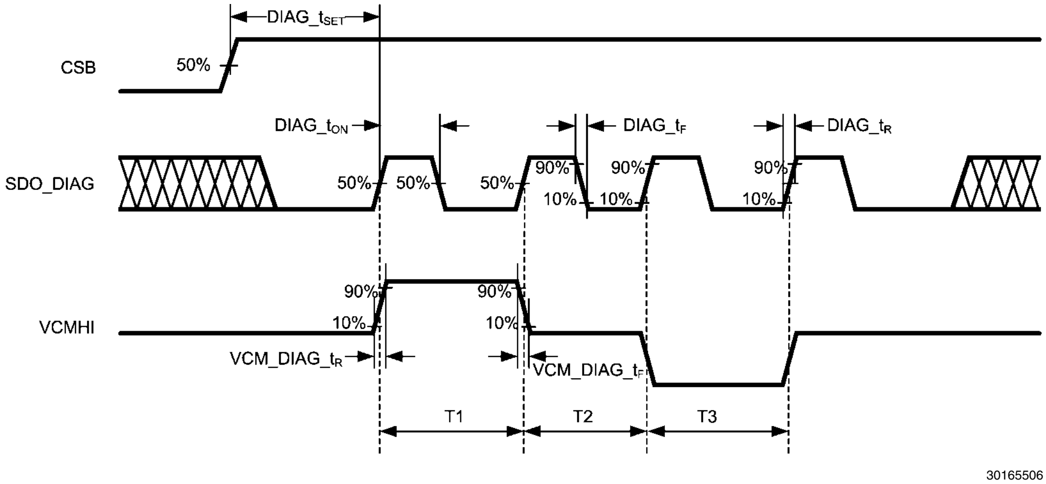
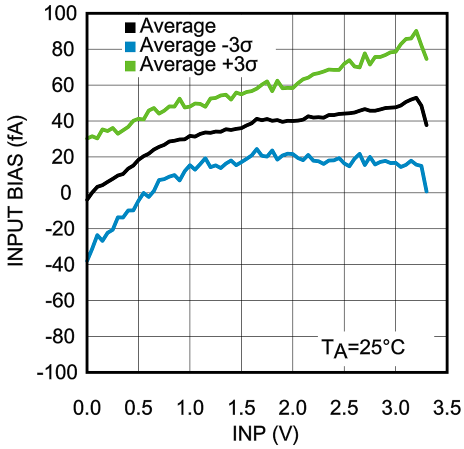


FIGURE 3. DIAGNOSTIC TIMING DIAGRAM

Typical Performance Characteristics

Unless otherwise specified, T_A=25°C, V_S=(VDD-GND)=3.3V, VREF=3.3V.

pH Buffer Input Bias Current vs. V_{INP} - Device ON



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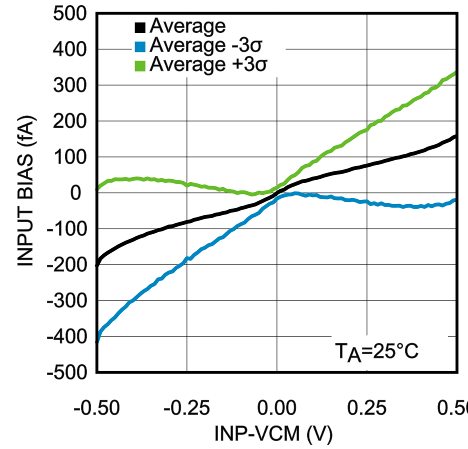
pH Buffer Input Bias Current vs. V_{INP} - Device OFF



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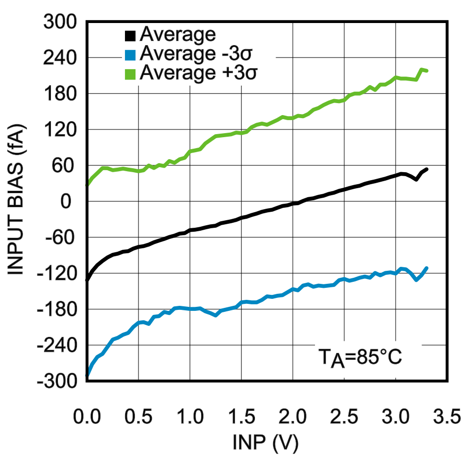
pH Buffer Input Bias Current vs. V_{INP} - Device ON



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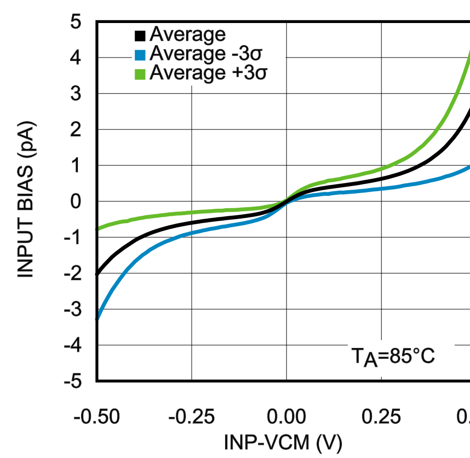
pH Buffer Input Bias Current vs. V_{INP} - Device OFF



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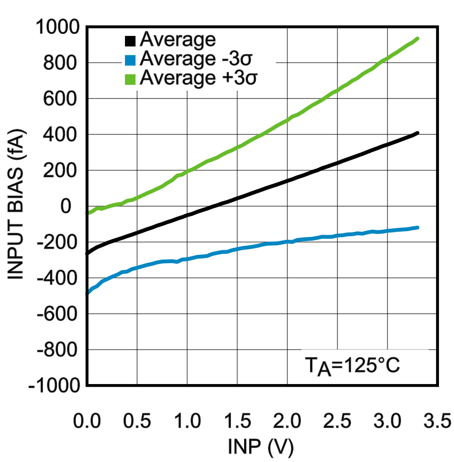
pH Buffer Input Bias Current vs. V_{INP} - Device ON



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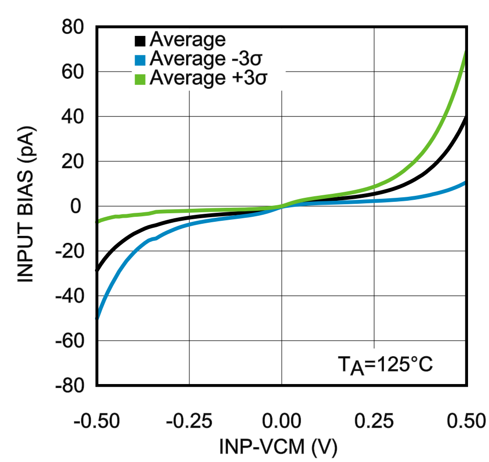
pH Buffer Input Bias Current vs. V_{INP} - Device OFF



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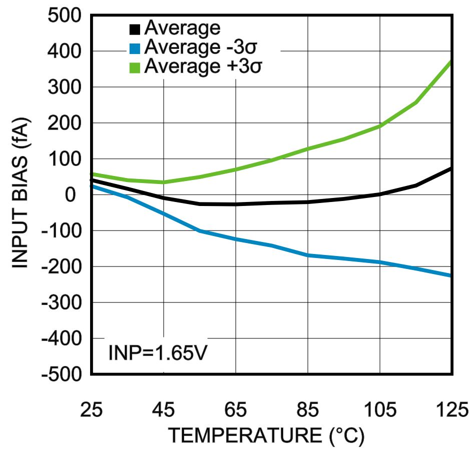
pH Buffer Input Bias Current vs. Temp - Device ON



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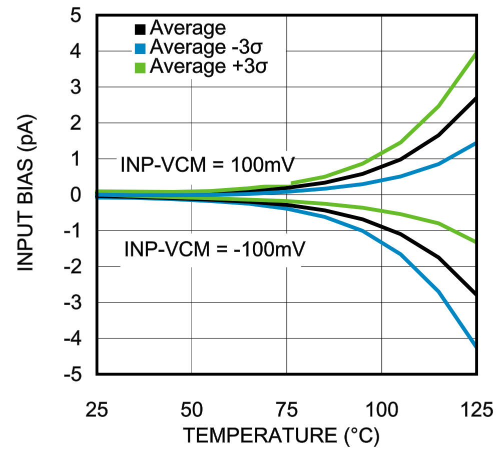
pH Buffer Input Bias Current vs. Temp - Device OFF



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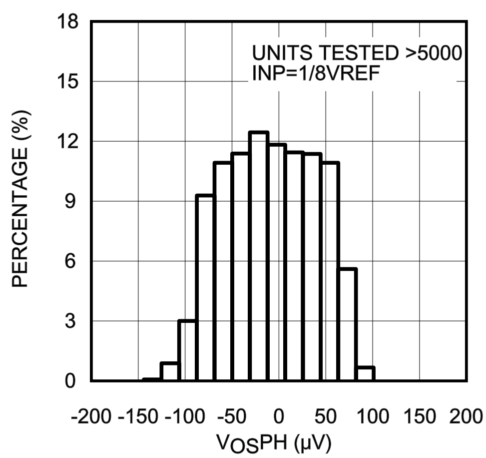
pH Buffer Input Voltage Offset



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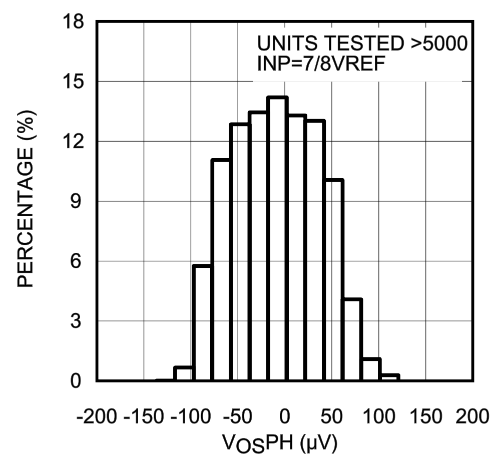
pH Buffer Input Voltage Offset



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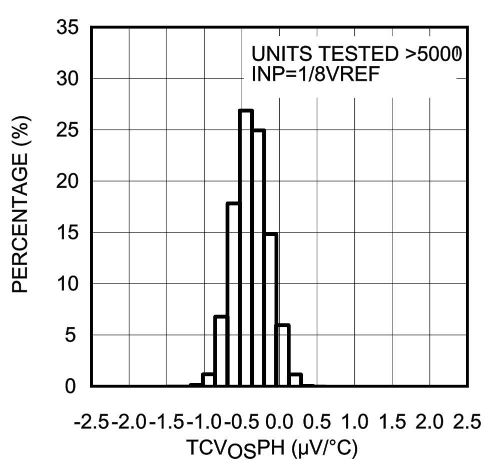
pH Buffer TcVos



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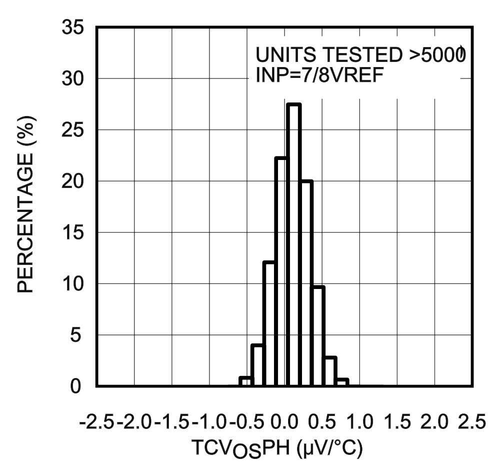
pH Buffer TcVos



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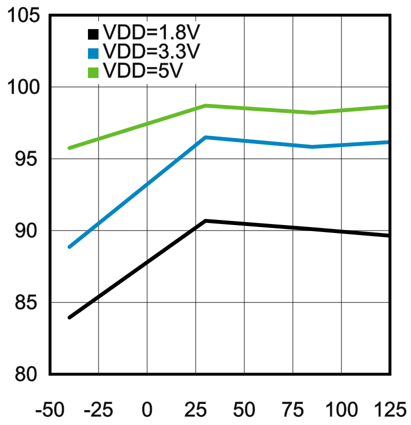
pH Buffer DC CMRR vs. Temperature



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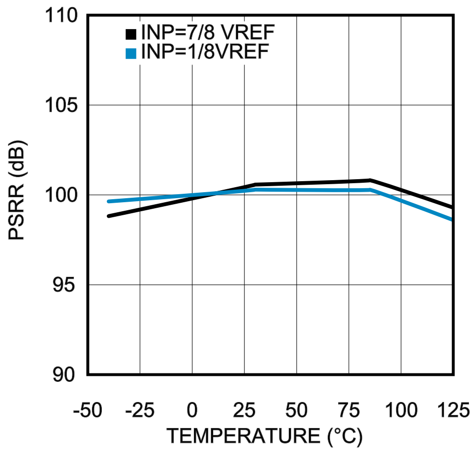
pH Buffer DC PSRR vs. Temperature



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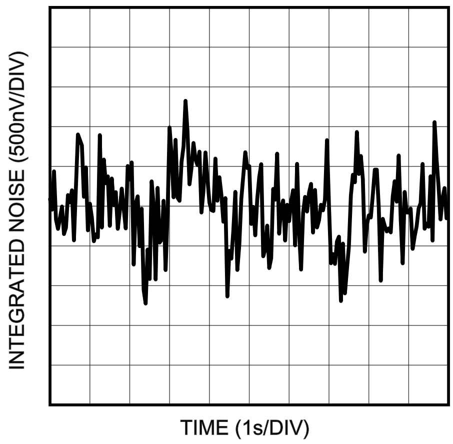
pH Buffer Time domain Voltage Noise



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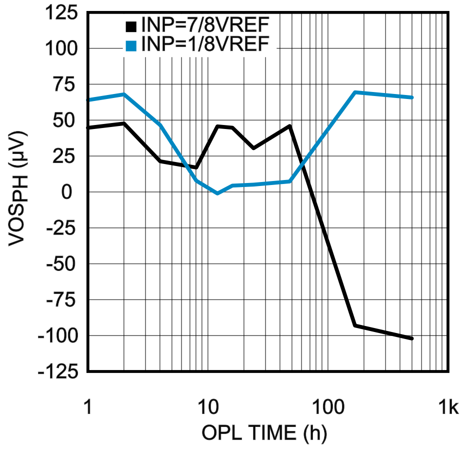
pH Buffer Input Offset Voltage Drift



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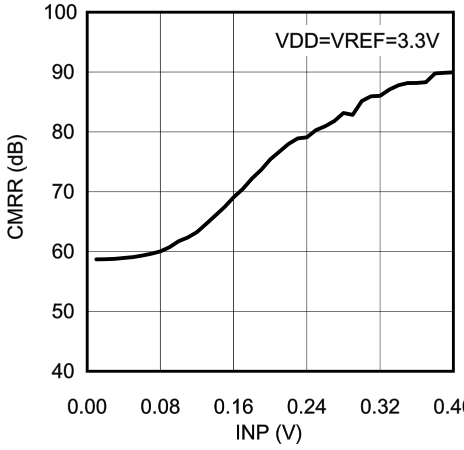
pH Buffer CMRR vs. V_{INP} - lower rail



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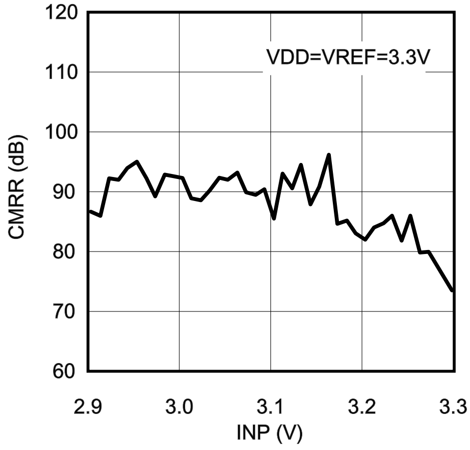
pH Buffer CMRR vs. V_{INP} - upper rail



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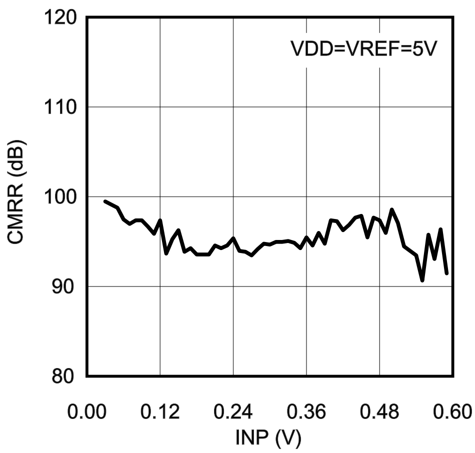
pH Buffer CMRR vs. V_{INP} - lower rail



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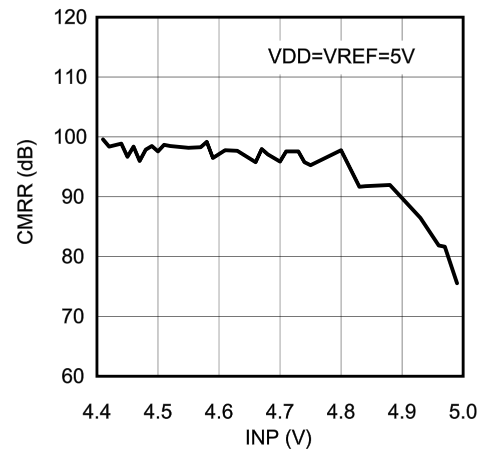
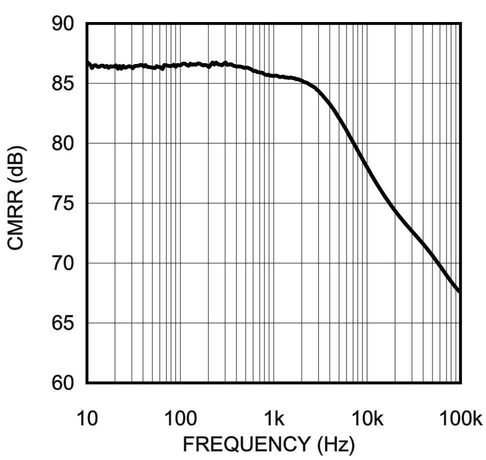
pH Buffer CMRR vs. V_{INP} - upper rail



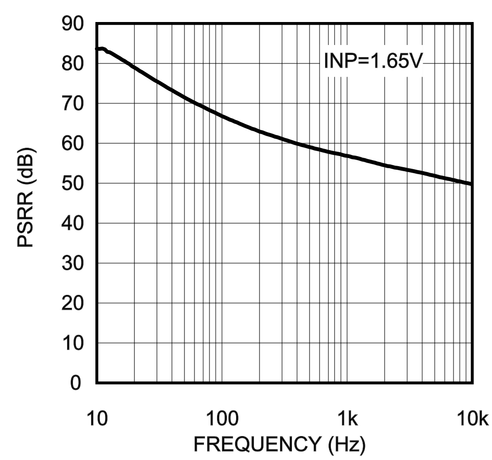
30165573

pH Buffer CMRR vs. Frequency



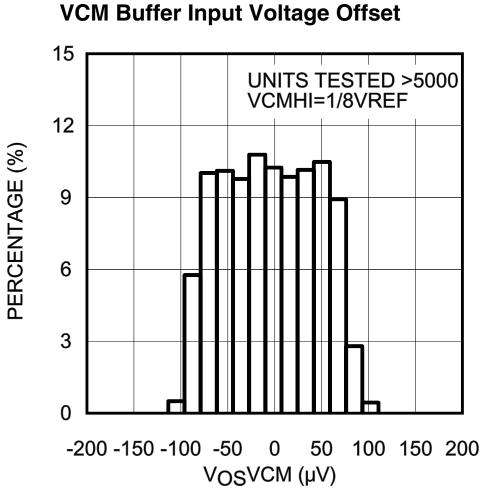
30165519

pH Buffer PSRR vs. Frequency



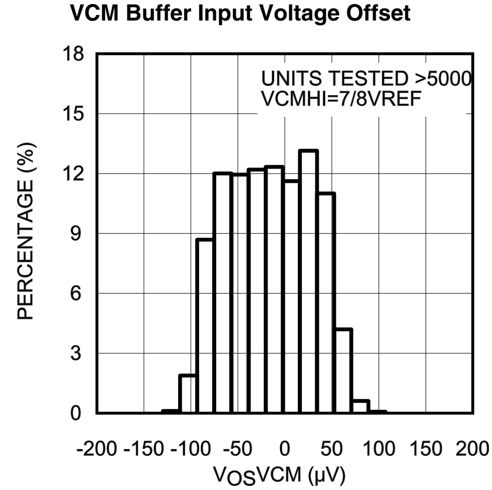
30165520

VCM Buffer Input Voltage Offset



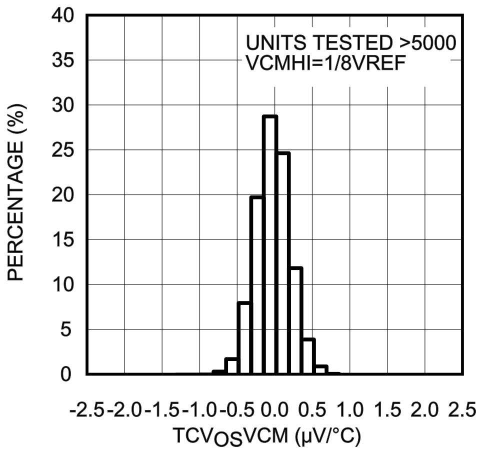
30165542

VCM Buffer Input Voltage Offset



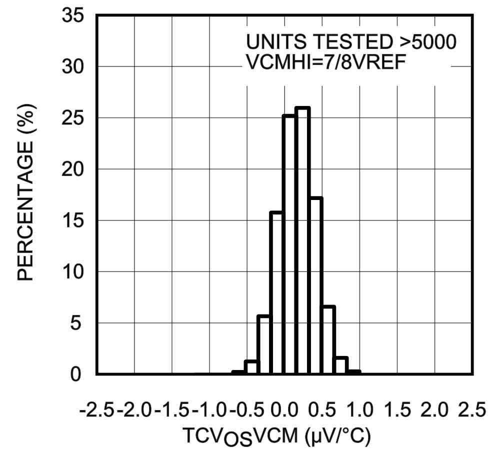
30165543

VCM Buffer TcVos



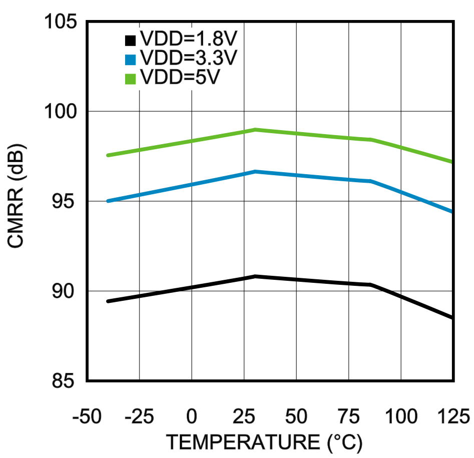
30165551

VCM Buffer TcVos



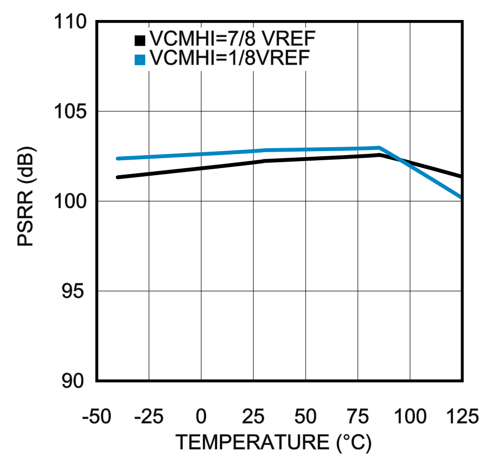
30165552

VCM Buffer DC CMRR vs. Temperature



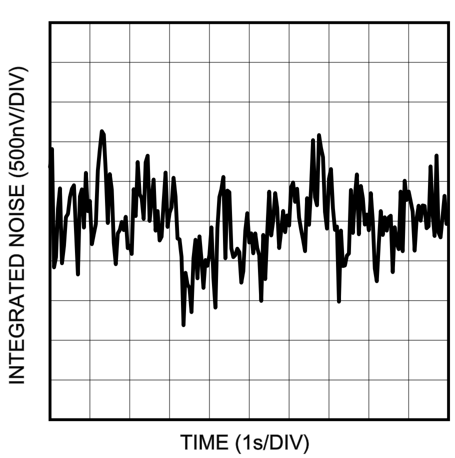
30165521

VCM Buffer DC PSRR vs. Temperature



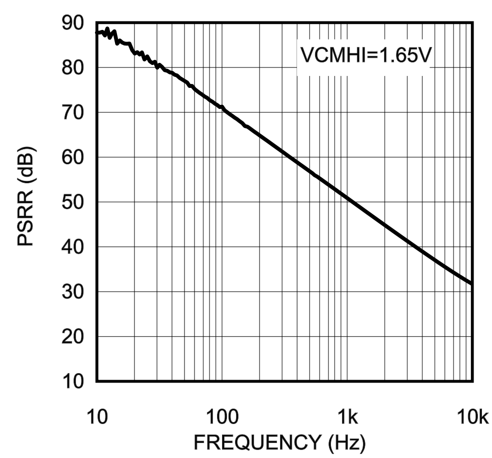
30165522

VCM Buffer Time domain Voltage Noise



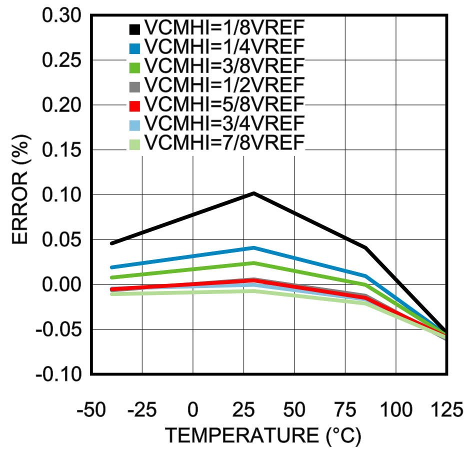
30165526

VCM Buffer PSRR vs. Frequency



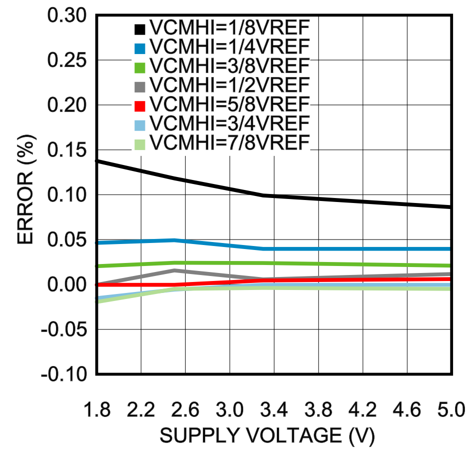
30165529

VCMHI error vs. Temp



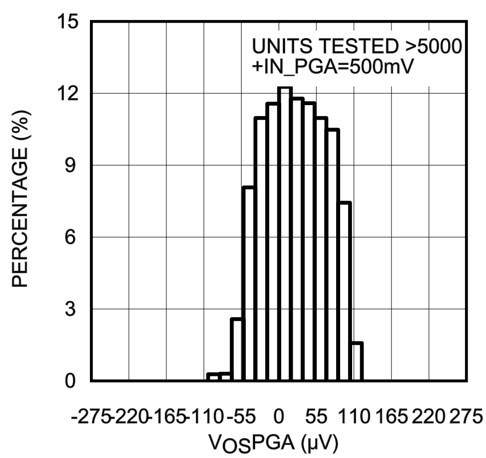
30165525

VCMHI error vs. Supply Voltage



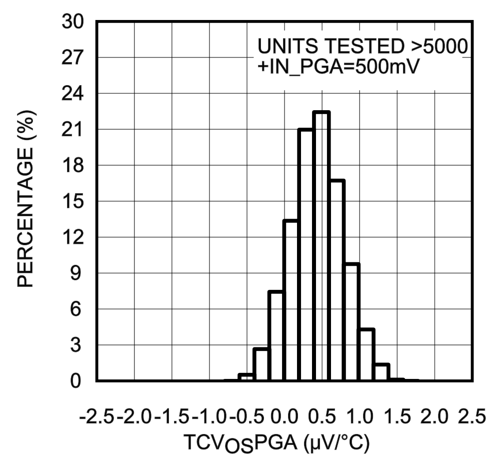
30165568

PGA Input Voltage Offset



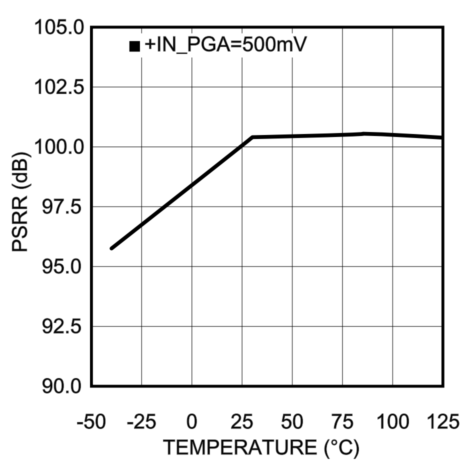
30165544

PGA TcVos



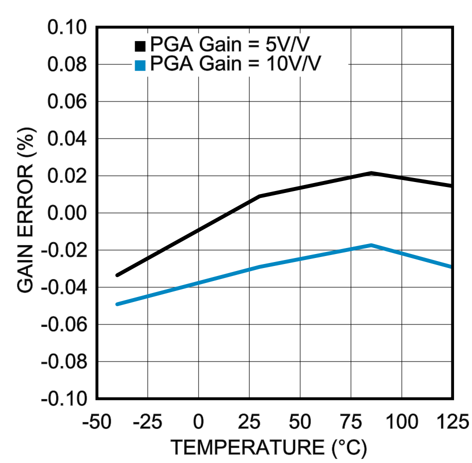
30165553

PGA DC PSRR vs. Temperature



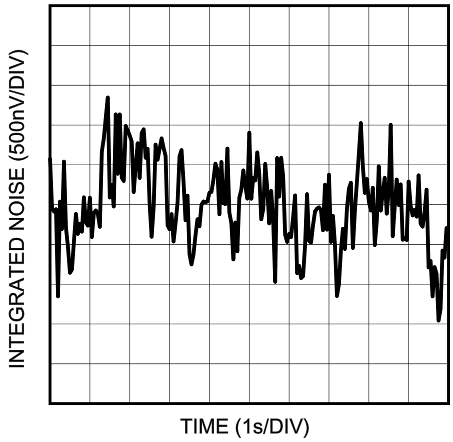
30165560

PGA Gain error vs. Temp



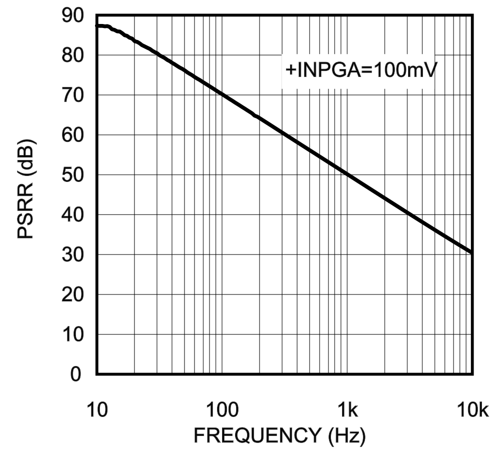
30165531

PGA Time domain Voltage Noise



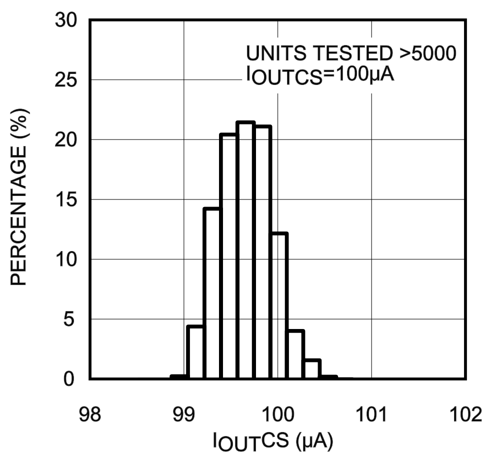
30165532

PGA PSRR vs. Frequency



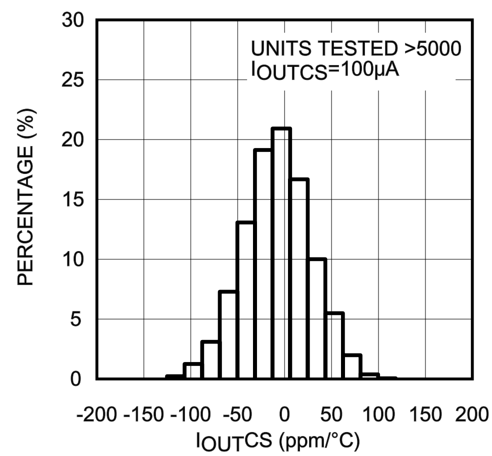
30165534

Current Source (I_{cs}=100µA)



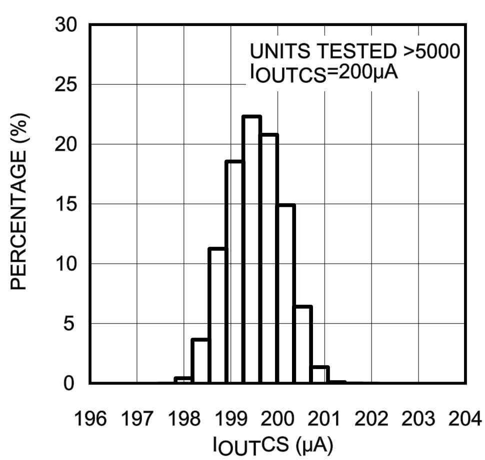
30165545

Temperature coefficient Current Source (I_{cs}=100µA)



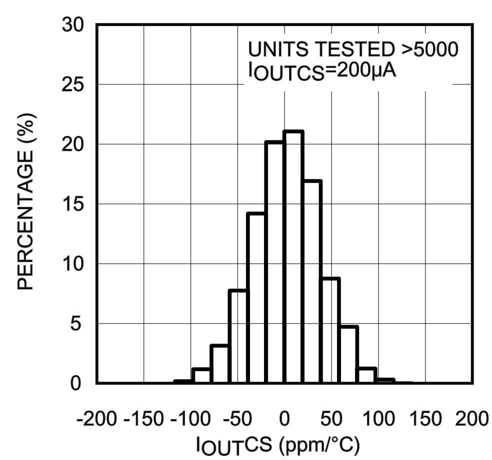
30165554

Current Source (I_{cs}=200µA)



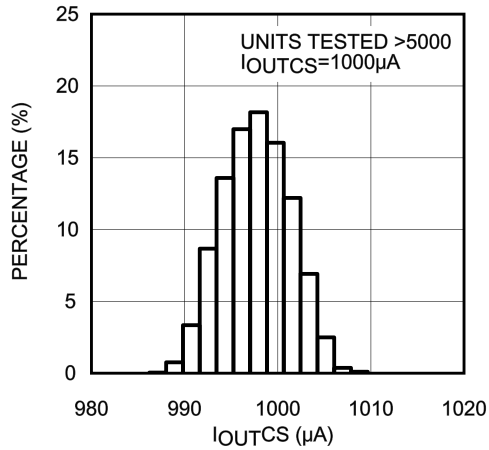
30165546

Temperature coefficient Current Source (I_{cs}=200µA)



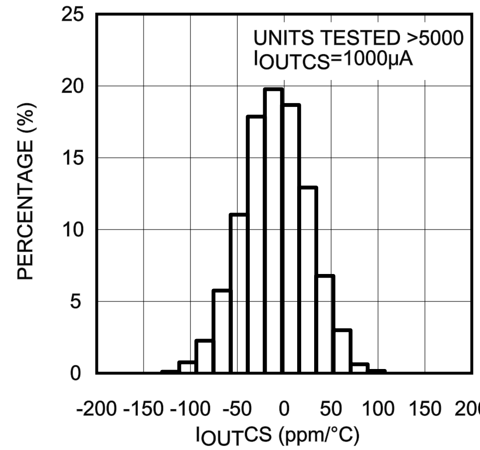
30165555

Current Source (I_{cs}=1000µA)



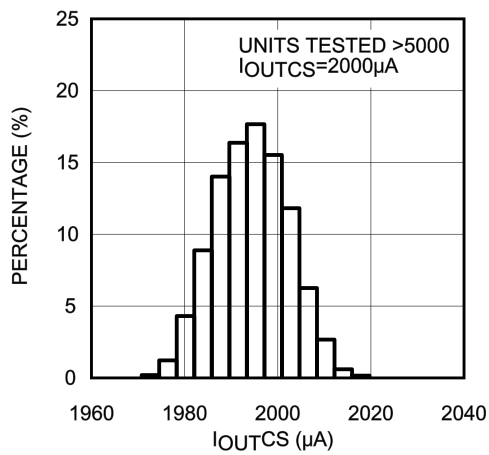
30165547

Temperature coefficient Current Source (I_{cs}=1000µA)



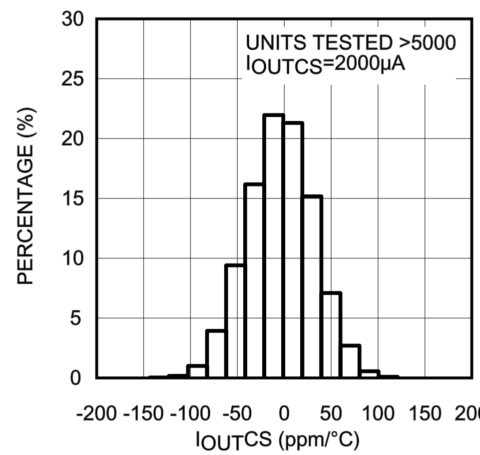
30165556

Current Source (I_{cs}=2000µA)



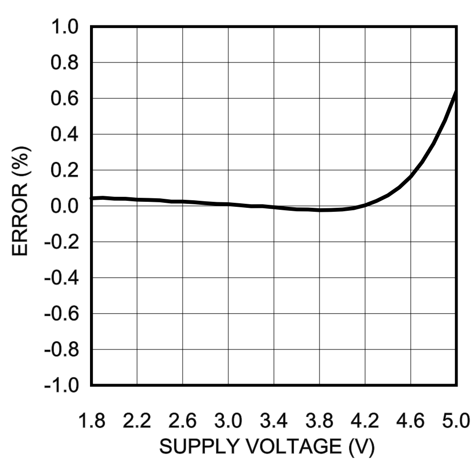
30165548

Temperature coefficient Current Source (I_{cs}=2000µA)



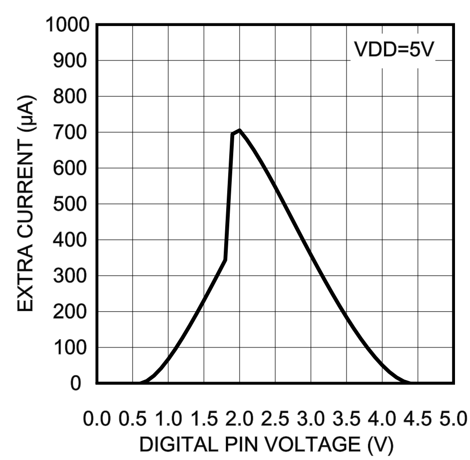
30165557

Current Source accuracy (I_acc$_{CS}$) vs. Supply Voltage



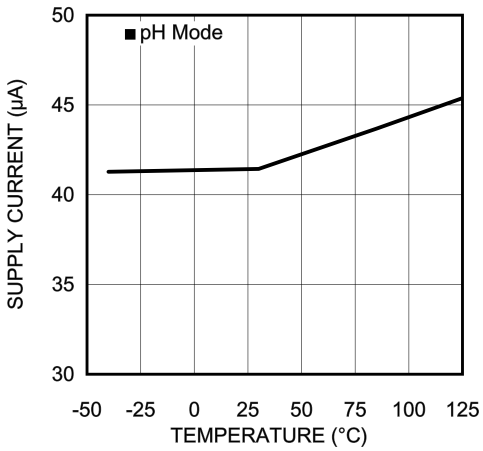
30165536

Supply current vs. digital input voltage



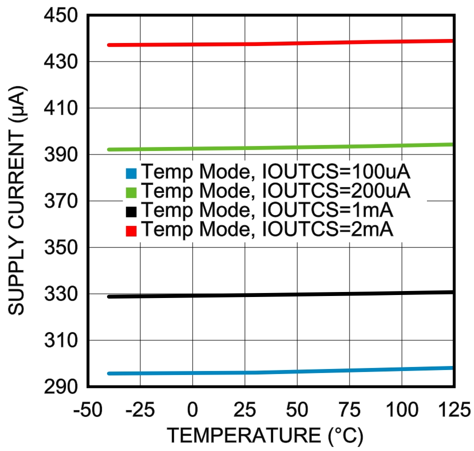
30165537

Supply current (pH Mode) vs. Temperature



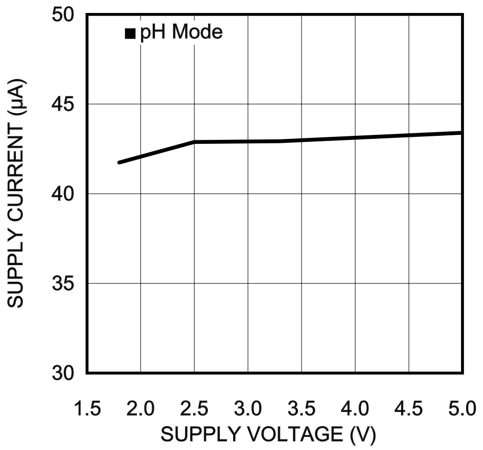
30165561

Supply current (Temp Mode) vs. Temperature



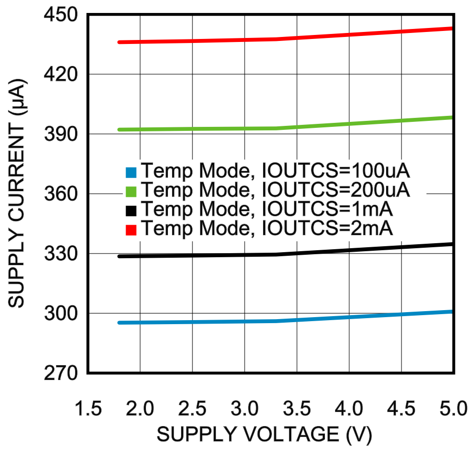
30165538

Supply current (pH Mode) vs. Supply Voltage



30165562

Supply current (Temp Mode) vs. Supply Voltage



30165539

Functional Description

GENERAL INFORMATION

The LMP91200 is a configurable sensor AFE for use in low power analytical sensing applications. The LMP91200 is designed for 2-electrode sensors. This device provides all of the functionality needed to detect changes based on a delta voltage at the sensor. Optimized for low-power applications, the LMP91200 works over a voltage range of 1.8V to 5.5V. With its extremely low input bias current it is optimized for use with pH sensors. Also in absence of supply voltage the very low input bias current reduces degradation of the pH probe when connected to the LMP91200. The Common Mode Output pin (VOCM) provides a common mode offset, which can be programmed to different values to accommodate pH sensor output ranges. For applications requiring a high impedance common mode this option is also available. Two guard pins provide support for high parasitic impedance wiring. Support for an external Pt1000, Pt100, or similar temperature sensor is integrated in the LMP91200. The control of this feature is available through the SPI interface. Additionally, a user controlled sensor diagnostic test is available. This function tests the sensor for proper connection and functionality.

pH Buffer

The pH Buffer is a unity gain buffer with a input bias current in the range of tens fA at room. Its very low bias current introduces a negligible error in the measurement of the pH. The ph buffer is provided with 2 guard pins (GUARD1, GUARD2) in order to minimize the leakage of the input current and to make easy the design of a guard ring.

Common mode selector and VCM buffer

The common mode selector allows to set 7 different values of common mode voltage (from 1/8 VREF to 7/8VREF with 1/8 VREF step) according to the applied voltage reference at VREF pin. Both buffered and unbuffered version of the set common mode voltage are available respectively at VCM pin and VCMHI pin. A copy of the buffered version is present at VOCM pin in case of differential measurement.

Current Source and PGA

The internal current source is programmable current generator which is able to source 4 different current values (100µA, 200µA, 1mA, 2mA) in order to well stimulate Pt100 and Pt1000 thermal resistor. The selected current is sourced from either RTD pin (pin for thermal resistor connection) or CAL pin (pin for reference resistor connection). The voltage across either the thermal resistor or the reference resistor is amplified by the PGA (5V/V, 10V/V) and provided at the VOUT pin when the LMP91200 is set in Temperature measurement mode.

Output Muxes

The output of the LMP91200 can be configured to support both differential and single ended ADC's. When measuring pH the Output signal can be referred either to VCM or GND. When measuring temperature the Output signal is referred to GND. The Output configuration is controlled through the SPI interface.

SERIAL CONTROL INTERFACE OPERATION

All the features of the LMP91200 (Mode of Operation, PGA Gain, Voltage reference, Diagnostic) are by data stored in a programming register. Data to be written into the control register is first loaded into the LMP91200 via the serial interface. The serial interface employs a 16-bit shift register. Data is loaded through the serial data input, SDI. Data passing through the shift register is output through the serial data output, SDO_DIAG. The serial clock, SCK controls the serial loading process. All sixteen data bits are required to correctly program the LMP91200. The falling edge of CSB enables the shift register to receive data. The SCK signal must be high during the falling and rising edge of CSB. Each data bit is clocked into the shift register on the rising edge of SCLK. Data is transferred from the shift register to the holding register on the rising edge of CSB.

Configuration Register

Bit	Name	Description
D15	MEAS_MODE	**0 pH measurement (default)** 1 Temp measurement
D14	I_MUX	**0 RTD (default)** 1 CAL
[D13:D12]	I_VALUE	**00 100µA (default)** 01 200 µA 10 1 mA 11 2 mA
D11	PGA	**0 5 V/V (default)** 1 10 V/V
[D10 :D8]	VCM	011 7/8Vref 010 3/4Vref 001 5/8Vref **000 1/2Vref (default)** 100 1/2Vref 101 3/8Vref 110 1/4Vref 111 1/8 Vref
D7	VOCM	**0 VOCM (default)** 1 GND
D6	DIAG_EN	**0 DIAG pin disabled (default)** 1 DIAG pin enabled
[D5 :D0]	RESERVED	RESERVED

Application Information

Theory of pH measurement

pH electrode measurements are made by comparing the readings in a sample with the readings in standards whose pH has been defined (buffers). When a pH sensing electrode comes in contact with a sample, a potential develops across the sensing membrane surface and that membrane potential varies with pH. A reference electrode provides a second, unvarying potential to quantitatively compare the changes of the sensing membrane potential. Nowadays pH electrodes are composed of a sensing electrode with the reference electrode built into the same electrode body, they are called combination electrodes. A high input impedance meter serves as the readout device and calculates the difference between the reference electrode and sensing electrode potentials in millivolts. The millivolts are then converted to pH units according to the Nernst equation.

Electrode behavior is described by the Nernst equation:

E = Eo + (2.3 RT/nF) log aH+, where

E is the measured potential from the sensing electrode,

Eo is related to the potential of the reference electrode,

(2.3 RT/nF) is the Nernst factor,

log aH+ is the pH, (aH+ = activity of Hydrogen ions).

2.3 RT/nF, includes the Gas Law constant (R), Faraday's constant (F), the temperature in degrees Kelvin (T) and the stoichiometric number of ions involved in the process (n). For pH, where n = 1, the Nernst factor is 2.3 RT/F. Since R and F are constants, the factor and therefore electrode behavior is dependent on temperature. The Nernst Factor is equivalent to the electrode slope which is a measure of the electrode response to the ion being detected. When the temperature is 25 °C, the theoretical Nernst slope is 59.16 mV/pH unit.

LMP91200 in pH meter with ATC (Automatic Temperature Compensation)

The most common cause of error in pH measurements is temperature. Temperature variations can influence pH for the following reasons:

the electrode slope will change with variations in temperature;

buffer and sample pH values will change with temperature.

Measurement drift can occur when the internal elements of the pH and reference electrodes are reaching thermal equilibrium after a temperature change. When the pH electrode and temperature probe are placed into a sample that varies significantly in temperature, the measurements can drift because the temperature response of the pH electrode and temperature probe may not be similar and the sample may not have a uniform temperature, so the pH electrode and temperature probe are responding to different environments.

The pH values of buffers and samples will change with variations in temperature because of their temperature dependent chemical equilibria. The pH electrode should be calibrated with buffers that have known pH values at different temperatures. Since pH meters are unable to correct sample pH values to a reference temperature, due to the unique pH versus temperature relationship of each sample, the calibration and measurements should be performed at the same temperature and sample pH values should be recorded with the sample temperature.

The LMP91200 offers in one package all the features to build a pH meter with ATC. Through the SPI Interface is possible to switch from pH measurement mode to temperature measurement mode and collect both temperature and potential of sensing electrode.

pH measurement

The output of a pH electrode ranges from 415 mV to –415 mV as the pH changes from 0 to 14 at 25°C. The output impedance of a pH electrode is extremely high, ranging from 10 MΩ to 1000 MΩ. The low input bias current of the LMP91200 allows the voltage error produced by the input bias current and electrode resistance to be minimal. For example, the output impedance of the pH electrode used is 10 MΩ, if an op amp with 3 nA of Ibias is used, the error caused due to this amplifier's input bias current and the source resistance of the pH electrode is 30 mV! This error can be greatly reduced to 1.25µV by using the LMP91200.

The pH measurement with the LMP91200 is straightforward, the pH electrode needs to be connected between VCM pin and INP pin. The voltage at VCM pin represent the internal zero of the system, so the potential of the electrode (voltage at INP pin) will be refered to VCM voltage. The common mode voltage can be set to well fit the input dynamic range of an external ADC connected between VOUT and VOCM when the LMP91200 is configured with differential output. In *Table 1* a typical configuration of the register of the LMP91200 with VCM set at 1/2 of VREF and differential output.

TABLE 1.

Bit	Name	Description
D15	MEAS_MODE	0 pH measurement
D14	I_MUX	Leave these bits as they have been configured for the temperature measurement.
[D13:D12]	I_VALUE	
D11	PGA	
[D10 :D8]	VCM	000 1/2 VREEF
D7	VOCM	0 VOCM
D6	DIAG_EN	0 DIAGNOSTIC disabled
[D5 :D0]	RESERVED	RESERVED

Configuration register: pH measurement

Temperature measurement

The LMP91200 supports temperature measurement with RTD like Pt100 and Pt1000. According to the RTD connected to the LMP91200 the right amount of exciting current can be programmed: 100µA for Pt1000 and 1mA for Pt100, resulting in a nominal voltage drop of 100mV for both RTD's at 0°C. This voltage can be amplified, using an internal amplifier with a factor of 5 or 10 V/V. In case of high precision temperature measurement it is possible to connect an external high accuracy resistor and implement a calibration procedure. The exciting current sourced by the LMP91200 can be multiplexed either into the RTD or into the external precision resistor in order to implement a 2-step or 3-step temperature measurement. The multi step temperature measurements allows to remove uncertainty of the temperature signal path.

1-step measurement

In the one step measurement the voltage across the RTD (Pt100, Pt1000) due to the exciting current is amplified and measured. The temperature can be calculated according to the following equation:

$$\mathbf{Temp(°C) = (Pt_{RES}\_calculated - Pt_{RES}\_nominal)/alpha} \quad (1)$$

where

alpha is the thermal coefficient of the RTD (it depends on the selected Ptres);

Pt_{RES}_nominal is the value of the Ptres at 0degC.

$$Pt_{RES}\_calculated = (VOUT\_Pt_{RES}/I\_Pt)/PGA\_GAIN \quad (2)$$

where

$VOUT\_Pt_{RES}$ is the amplified voltage across the RTD at VOUT pin (ground referred) when the LMP91200 is configured according to *Table 2*.

I_Pt is the value of the selected exciting current according to the RTD;

PGA_GAIN is the selected gain of the PGA.

Inserting *Equation 2* in *Equation 1* the temperature is given by the following equation:

$$Temp(°C) = Temp(°C) = ((VOUT\_Pt_{RES}/I\_Pt)/PGA\_GAIN – Pt_{RES}\_nominal)/alpha \quad (3)$$

TABLE 2.

Bit	Name	Description
D15	MEAS_MODE	1 Temp measurement
D14	I_MUX	0 RTD
[D13:D12]	I_VALUE	00 100µA (Pt1000) 10 1 mA (Pt100)
D11	PGA	1 10 V/V
[D10 :D8]	VCM	Leave these bits as they have been configured for the pH measurement.
D7	VOCM	1 GND
D6	DIAG_EN	0 DIAGNOSTIC disabled
[D5 :D0]	RESERVED	RESERVED

Configuration register: 1-step measurement

The 1-step temperature measurement has a precision of about ±3°C.

2-step measurement

This method requires 2 acquisitions and a precision resistor (R_{REF}) connected between CAL and GND pin, (the RTD is always connected between RTD and GND pin). The first acquisitions measure the voltage across the precision resistor in the same condition (source current and PGA gain) of the next temperature measurement in order to remove the uncertainty on the current source value. The second acquisition measures the voltage across the RTD (similar to the 1-step measure), in this case the formula to calculate the temperature is a little bit more complicate in order to take in account the non-ideality of the system (source current error).

$$Temp(°C) = (Pt_{RES}\_calculated – Pt_{RES}\_nominal) / alpha \quad (4)$$

where

alpha is the thermal coefficient of the RTD (it depends on the selected Ptres);

Ptres_nominal is the value of the Ptres at 0degC.

$$Pt_{RES}\_calculated=(VOUT\_Pt_{RES}/PGA\_GAIN)/I\_true \quad (5)$$

where

$VOUT\_Pt_{RES}$ is the amplified voltage across the RTD at VOUT pin (ground referred), when the LMP91200 is configured according to *Table 4*.

I_true is the real current which alternatively flows in the external precison resistance R_{REF} and in the RTD.

PGA_GAIN is the selected gain of the PGA.

$$I\_true=(VOUT\_R_{REF})/(PGA\_GAIN*R_{REF}) \quad (6)$$

where

$VOUT\_R_{REF}$ is the amplified voltage across the R_{REF} at VOUT pin (ground referred), when the LMP91200 is configured according to *Table 3*.

Inserting *Equation 5* and *Equation 6* in *Equation 4* the temperature is given by the following equation:

$$Temp(°C) = ((VOUT\_Pt_{RES} /VOUT\_R_{REF})*R_{REF}– Pt_{RES}\_nominal) /alpha \quad (7)$$

TABLE 3.

Bit	Name	Description
D15	MEAS_MODE	1 Temp measurement
D14	I_MUX	1 RCAL
[D13:D12]	I_VALUE	00 100µA (Pt1000) 10 1 mA (Pt100)
D11	PGA	1 10 V/V
[D10 :D8]	VCM	Leave these bits as they have been configured for the pH measurement.
D7	VOCM	1 GND
D6	DIAG_EN	0 DIAGNOSTIC disabled
[D5 :D0]	RESERVED	RESERVED

TABLE 4.

Bit	Name	Description
D15	MEAS_MODE	1 Temp measurement
D14	I_MUX	0 RTD
[D13:D12]	I_VALUE	00 100µA (Pt1000) 10 1 mA (Pt100)
D11	PGA	1 10 V/V
[D10 :D8]	VCM	Leave these bits as they have been configured for the pH measurement.
D7	VOCM	1 GND
D6	DIAG_EN	0 DIAGNOSTIC disabled
[D5 :D0]	RESERVED	RESERVED

Configuration register: 2-step measurement

The 2-step temperature measurement has a precision of about ±0.3°C (with R_{REF} @ 0.01% of tolerance) which is good enough in most of pH meter applications.

3-step measurement

This method requires 3 acquisitions and a precision resistor (R_{REF}) connected between CAL and GND pin, (the RTD is always connected between RTD and GND pin). The first two acquisitions measure the voltage across the precision resistor in 2 different conditions (2 different exciting current and 2 PGA gains) in order to remove the uncertainty of the current source value and the offset of the path. The third acquisition measures the voltage across the RTD (similar to the 1-step measure), in this case the formula to calculate the temperature is more complicate in order to take in account the non-ideality of the system (offset, source current error).

$$\text{Temp}(^{\circ}\text{C}) = (\text{Pt}_{\text{RES}}\_\text{calculated} - \text{Pt}_{\text{RES}}\_\text{nominal}) / \text{alpha} \quad (8)$$

where

alpha is the thermal coefficient of the RTD (it depends on the selected Ptres);

Ptres_nominal is the value of the Ptres at 0degC.

$$\text{Pt}_{\text{RES}}\_\text{calculated}=((\text{VOUT}\_\text{Pt}_{\text{RES}}/\text{PGA}\_\text{GAIN})-\text{Vos})/\text{I}\_\text{true} \quad (9)$$

where

VOUT_Pt$_{RES}$ is the amplified voltage across the RTD at VOUT pin (ground referred), when the LMP91200 is configured according to *Table 7*.

I_true is the real current which alternatively flows in the external precison resistance R_{REF} and in the RTD.

PGA_GAIN is the selected gain of the PGA.

Vos is the offset of the path.

$$\text{Vos}=(\text{VOUT}\_\text{R}_{\text{REF0}}-\text{VOUT}\_\text{R}_{\text{REF1}})/5 \quad (10)$$

where

VOUT_R$_{REF0}$ is the amplified voltage across the R_{REF} at VOUT pin (ground referred), when the LMP91200 is configured according to *Table 5*.

VOUT_R$_{REF\ 1}$ is the amplified voltage across the R_{REF} at VOUT pin (ground referred), when the LMP91200 is configured according to *Table 6*.

$$\text{I}\_\text{true}=(2^{*}\text{VOUT}\_\text{R}_{\text{REF1}}-\text{VOUT}\_\text{R}_{\text{REF0}})/(10^{*}\text{R}_{\text{REF}}) \quad (11)$$

Inserting *Equation 9*, *Equation 10* and *Equation 11* in *Equation 8* the temperature is given by the following equation:

$$\text{Temp}(^{\circ}\text{C}) = (((\text{VOUT}\_\text{Pt}_{\text{RES}}/\text{PGA}\_\text{GAIN})-(\text{VOUT}\_\text{R}_{\text{REF0}}-\text{VOUT}\_\text{R}_{\text{REF1}})/5)/((2^{*}\text{VOUT}\_\text{R}_{\text{REF1}}-\text{VOUT}\_\text{R}_{\text{REF0}})/(10^{*}\text{R}_{\text{REF}}))-\text{Pt}_{\text{RES}}\_\text{nominal})/\text{alpha} \quad (12)$$

TABLE 5.

Bit	Name	Description
D15	MEAS_MODE	1 Temp measurement
D14	I_MUX	1 RCAL
[D13:D12]	I_VALUE	01 200μA (Pt1000) 11 2 mA (Pt100)
D11	PGA	0 5 V/V
[D10 :D8]	VCM	Leave these bits as they have been configured for the pH measurement.
D7	VOCM	1 GND
D6	DIAG_EN	0 DIAGNOSTIC disabled
[D5 :D0]	RESERVED	RESERVED

TABLE 6.

Bit	Name	Description
D15	MEAS_MODE	1 Temp measurement
D14	I_MUX	1 RCAL
[D13:D12]	I_VALUE	00 100μA (Pt1000) 10 1 mA (Pt100)
D11	PGA	1 10 V/V
[D10 :D8]	VCM	Leave these bits as they have been configured for the pH measurement.
D7	VOCM	1 GND
D6	DIAG_EN	0 DIAGNOSTIC disabled
[D5 :D0]	RESERVED	RESERVED

TABLE 7.

Bit	Name	Description
D15	MEAS_MODE	1 Temp measurement
D14	I_MUX	0 RTD
[D13:D12]	I_VALUE	00 100μA (Pt1000) 10 1 mA (Pt100)
D11	PGA	1 10 V/V
[D10 :D8]	VCM	Leave these bits as they have been configured for the pH measurement.
D7	VOCM	1 GND
D6	DIAG_EN	0 DIAGNOSTIC disabled
[D5 :D0]	RESERVED	RESERVED

Configuration register: 3-step measurement

The 3-step temperature measurement can reach a precision as high as ±0.1°C (with R_{REF} @ 0.01% of tolerance) when the analog signal is acquired by at least 16 bit ADC. With lower number of bit ADC this method gives the same result of the 2-step measurement due to the low voltage offset of the signal path. As rule of thumb, the 3-step temperature measurement gives good result if he the LSB of the ADC is less than the input offset of the PGA.

Diagnostic Feature

The diagnostic function allows detecting the presence of the sensor and checking the connection of the sensor. A further analysis of the answer of the pH probe to the diagnostic stimulus allows estimating the aging of the pH probe. With the diagnostic function is possible to change slightly (+/- 5% VREF) the Common mode voltage. If the sensor is present it reacts, this reaction gives some information on the status of the connection, the presence of the sensor and its aging. In fact a typical symptom of the aging of a pH probe is the slowness in the answer. It means that a pH probe answers with a smoother step to the diagnostic stimulus as its age increases.

The procedure is enabled and disabled by SPI (refer to *Configuration Register*). Until bit D6 is at low logic level, VCM stays at the programmed voltage independently by the SDO_DIAG pin status. When bit D6 is tied at high logic level, on the first rising edge of SDO_DIAG, a positive pulse is generate. At the second positive rising edge of SDO_DIAG pin, the positive pulse ends. At the third positive rising edge of SDO_DIAG a negative pulse is generated. At the forth positive rising edge of the SDO_DIAG the negative pulse ends and the routine is stopped and cannot restart until bit D6 is set again at 1.

Layout Consideration

In pH measurement, due to the high impedance of the ph Electrode, careful circuit layout and assembly are required. Guarding techniques are highly recommended to reduce parasitic leakage current by isolating the LMP91200's input from large voltage gradients across the PC board. A guard is a low impedance conductor that surrounds an input line and its potential is raised to the input line's voltage. The input pin should be fully guarded as shown in *Figure 4*.The guard traces should completely encircle the input connections. In addition, they should be located on both sides of the PCB and be connected together. The LMP91200 makes the guard ring easy to be implemented without any other external op amp. The ring needs to be connected to the guard pins (GUARD1 and GUARD2) which are at the same potential of the INP pin. Solder mask should not cover the input and the guard area including guard traces on either side of the PCB. Sockets are not recommended as they can be a significant leakage source. After assembly, a thorough cleaning using commercial solvent is necessary.

In *Figure 4* is showed a typical guard ring circuit when the LMP912000 is interfaced to a pH probe trough a triaxial cable/connector, usually known as 'TRIAX'. The signal conductor and the guard of the triax should be kept at the same potential; therefore, the leakage current between them is practically zero. Since triax has an extra layer of insulation and a second conducting sheath, it offers greater rejection of interference than coaxial cable/connector.

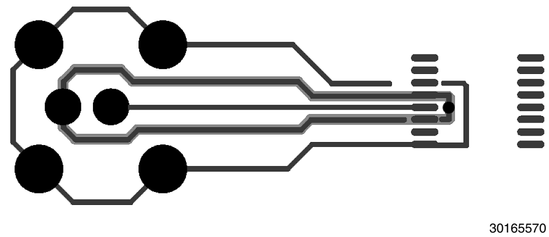
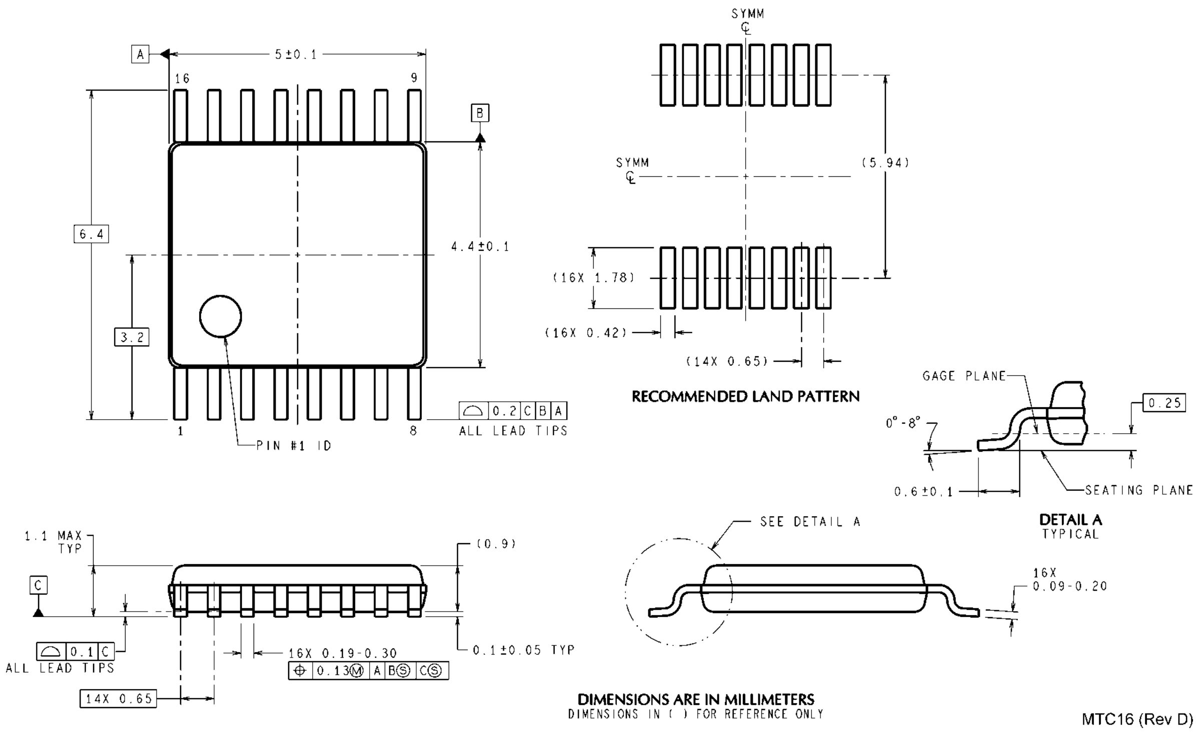


FIGURE 4. Circuit Board Guard Layout

Physical Dimensions inches (millimeters) unless otherwise noted



16-Pin TSSOP
NS Package Number MTC16

Notes