

## Low-input bias-current front end SAR ADC circuit

Mike Stout

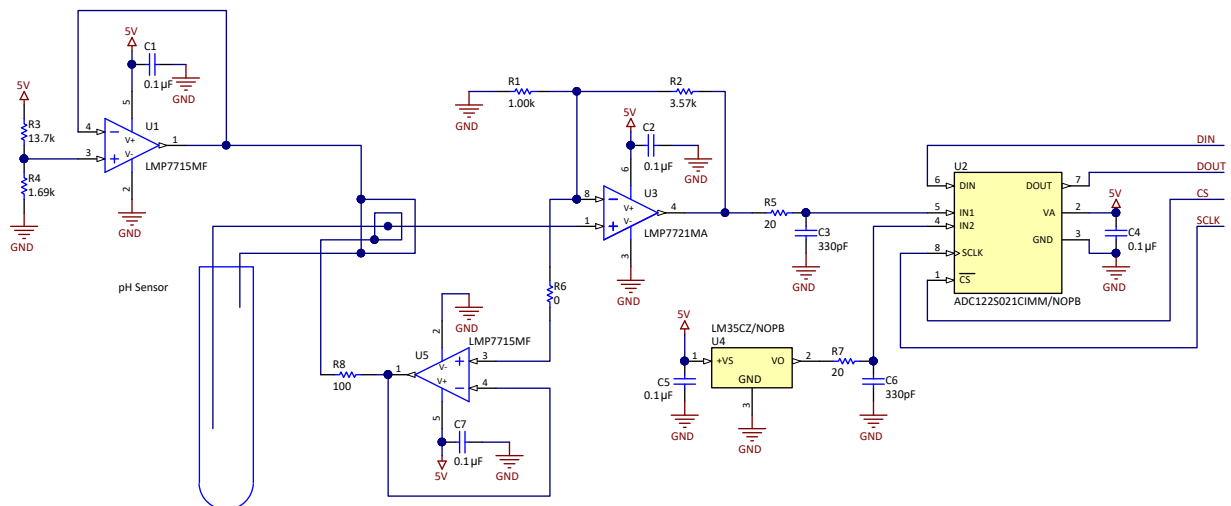
Input	ADC Input	Digital Output <b>ADC122S021</b>
VinMin = 0.03V	IN1 = 0.14	115 = 0x073
VinMax = 1.07V	IN1 = 4.88	3998 = 0xF9E
VinMin = 0V	IN2 = 0V	0 = 0x000
VinMax = 1V	IN2 = 1V	819 = 0x333

Power Supplies	
V+, VA	V–
5V	0V

### Design Description

This design shows a low  $I_{bias}$  amplifier being used to drive a SAR ADC. A sensor with high output impedance requires an amplifier with a low input bias current to minimize errors. Examples of applications where this type of sensor might be used include *gas detectors*, *blood gas analyzers*, and *air quality detectors*. In this design, a pH probe is used for the sensor. The output impedance of a pH probe can be from  $10M\Omega$  to  $1000M\Omega$ . If a pH probe is used that has an output impedance of  $10M\Omega$  with an op amp that has  $3nA$  of input bias current, the error due to the input bias current of the op amp will be  $30mV$ . Using the input signal amplitude and gain described in the *component selection* section, this  $30mV$  equates to an error of about 2.9%. If an op amp with an input bias current of  $3fA$  is used, the error is decreased to  $30nV$ .

The output of the pH sensor does not quickly change, so a lower speed ADC can be used. The value from the pH sensor changes as the temperature changes so a two channel ADC was selected so that one channel could be used to monitor the temperature. The ADC122S021 used in this design is a 2-channel, 12-bit, ADC that can sample up to 200ksps.



## Specifications

Specification	Calculated	Simulated	Measured
I <sub>bias</sub>	20fA	118fA	20fA

### Design Notes

1. Use COG (NPO) capacitors for C3 and C6.
2. Each IC should have a bypass capacitor of 0.1μF.
3. PCB layout is very important. See the [LMP7721 Multi-Function Evaluation Board Users' Guide](#).
4. The PCB must be clean. See the [LMP7721 Multi-Function Evaluation Board Users' Guide](#).
5. For more information on low leakage design, see [Design femtoampere circuits with low leakage](#).

### Component Selection

1. The output voltage of a pH sensor changes as the temperature changes. At 0°C it outputs 54.2mV/pH, at 25°C it outputs 59.16mV/pH, and at 100°C it outputs 74.04mV/pH. This means that the maximum swing of the pH sensor around the bias point of the pH sensor will be ±518.3mV at 100°C. The maximum output of the LMP7721 should be limited to ±2.4V to allow for headroom. That sets the gain of the LMP7721 at:  

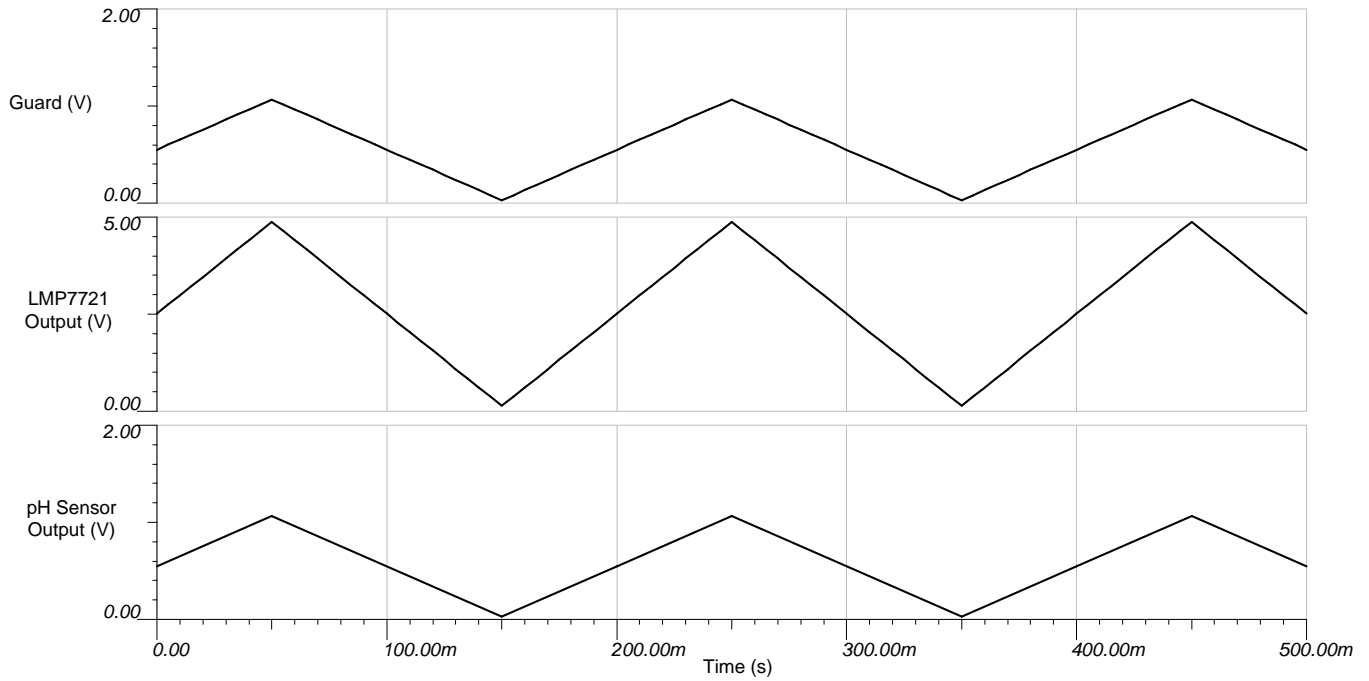
$$2.4V / 0.5183V = 4.6V/V$$
 Setting resistors R2 = 3.57kΩ and R1 = 1kΩ, will set this gain.
2. Since the input of the LMP7721 must be from 0V to 5V, the pH sensor needs to be biased above ground. Resistors R3 = 13.7kΩ and R4 = 1.69kΩ in a voltage divider configuration will set the input of U1 to:  

$$5V \cdot 1.69k\Omega / (1.69k\Omega + 13.7k\Omega) = 549mV$$
 U1 has a gain of 1V/V so the bias of the pH sensor will also be at 549mV. Since the pH sensor can swing –518.3mV below the bias point, this keeps the input of the LMP7721 above ground. The output of the LMP7721 will be centered at:  

$$0.549V \cdot 4.6V/V = 2.52V$$
 and can swing ±2.4V above and below the center point.
3. U5 is used to set the voltage of the guard ring. It is set with a gain of 1V/V and the input is the signal on the –IN pin of the LMP7721.
4. The output of the LMP7721 is connected to one of the inputs of the ADC122S021 SAR ADC. The sampling capacitor of the ADC is 33pF and the external capacitor placed next to the pin of the ADC should be 10 times larger, or 330pF. A small resistor of 20Ω is added in series to isolate the capacitor from the LMP7721.
5. Because the output of the pH sensor changes as the temperature changes the LM35, a temperature sensor, is connected to channel 2 of the ADC122S021. A 330-pF capacitor along with a 20-Ω series resistor is used on the output of the temperature sensor.

### DC Transfer Characteristics

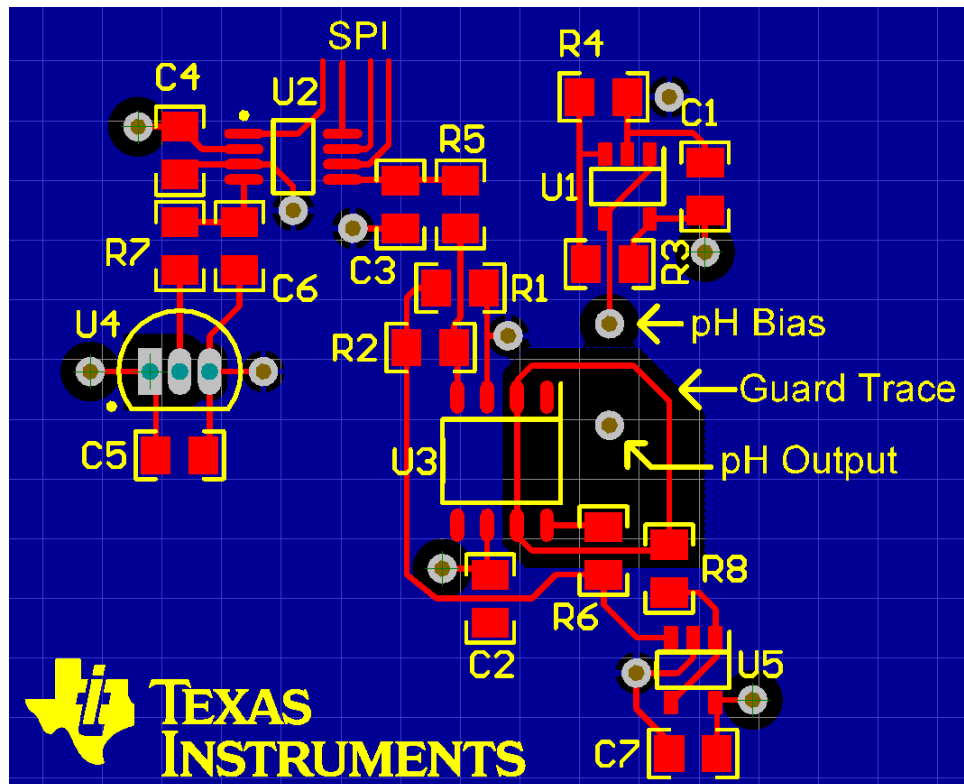
The following graph shows the pH sensor input to the LMP7721, the Guard voltage, and the LMP7721 output. This data is for 100°C, when the pH sensor output has the largest possible output swing.



## Layout

The PCB layout is very important for a low I<sub>bias</sub> circuit. Current leakage will occur between two traces when there is a voltage potential between the traces. This is the reason for the guard trace. The guard trace is set to a voltage close to the input voltage to minimize the leakage between the input of the LMP7721 and the outside world. The LMP7721 includes two unused pins (pins 2 and 7) that can be used to simplify the layout of a guard trace.

The following image shows a sample layout. The output of the pH sensor and the +IN input of the LMP7721 are separated from the rest of the circuit by the guard trace, which is close to the input voltage. This will minimize the leakage on the input of the LMP7721. The bias of the pH sensor is located outside of the guard. Leakage between the bias point and the rest of the circuit is not important. Solder mask should not cover the area inside the guard trace. If there is a ground plane on the bottom side of the board or other internal planes, they should have a 'keep out' area underneath the guard area.



## Design Featured Devices

Device	Key Features	Link	Similar Devices
<a href="http://www.ti.com/product/adc122s021">ADC122S021</a>	12 bit, SPI, 2 channel, 50ksps to 200ksps, single ended input	<a href="http://www.ti.com/product/adc122s021">www.ti.com/product/adc122s021</a>	<a href="http://www.ti.com/adcs">www.ti.com/adcs</a>
<a href="http://www.ti.com/product/lmp7721">LMP7721</a>	Ultra-low input bias current of 3fA, with a specified limit of $\pm 20$ fA at 25°C, offset voltage $\pm 26$ $\mu$ V, GBW 17MHz	<a href="http://www.ti.com/product/lmp7721">www.ti.com/product/lmp7721</a>	<a href="http://www.ti.com/opamps">www.ti.com/opamps</a>
<a href="http://www.ti.com/product/lmp7715">LMP7715</a>	Input offset voltage $\pm 150$ $\mu$ V, input bias current 100fA, input voltage noise 5.8nV/ $\sqrt{\text{Hz}}$ , gain bandwidth product 17MHz	<a href="http://www.ti.com/product/lmp7715">www.ti.com/product/lmp7715</a>	<a href="http://www.ti.com/opamps">www.ti.com/opamps</a>
<a href="http://www.ti.com/product/lm35">LM35</a>	Calibrated directly in degrees Celsius, Linear + 10-mV/°C scale factor, 0.5°C ensured accuracy (at 25°C), rated for full -55°C to 150°C range	<a href="http://www.ti.com/product/lm35">www.ti.com/product/lm35</a>	<a href="http://www.ti.com/temperature">www.ti.com/temperature</a>

## Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

## Revision History

Revision	Date	Change
A	March 2019	Downstyle the title and changed title role to 'Data Converters'. Added link to circuit cookbook landing page.

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](#) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2021, Texas Instruments Incorporated