

Offset Compensation Technique Improves Bridge-Configured Sensor Performance

DENNIS SEGUINE | CYPRESS SEMICONDUCTOR CORP. seg@cypress.com

STRAIN GAGES AND pressure sensors usually are connected in a bridge configuration. These sensors have a typical full-scale sensitivity of 3.0 to 5.0 millivolts per volt (mV/V) of excitation, though some may be as low as 1.0 mV/V. This level is intended to improve linearity while minimizing mechanical stress in the sensor, but at the expense of the signal level.

One way to increase the signal level is to increase the excitation level. But if the system works from a single 3.3- or 5.0-V supply, this may not be an option. Usually, substantial gain must be added to get the signal into the range of a reasonable analog-to-digital converter (ADC).

Most systems digitize sensor data, then either display it or perform some control function. That means a microcontroller is available to control gains and connections. The op amps inside typical microcontrollers have input offset voltages that are higher than what can be used directly in some applications.

For example, with a 5.0-mV/V sensor and 5.0-V sensor drive, full scale is 25.0 mV. An instrumentation amplifier built using op amps with input offset of 3.0 mV uses up to 24% of the available range. Further, an offset drift of 15 $\mu\text{V}/^\circ\text{C}$ yields an error of 1.8% of full scale over as little as 30°C of range, even if you calibrate out the offset at startup.

There is a solution to the offset, drift, and low-frequency noise problem by taking advantage of the switches on the microcontroller analog inputs to switch signals around to subtract the offset voltage. The Cypress PSoC, for example, has multiplexable inputs to differential and instrumentation amplifiers.

A model shows the standard connection with the offsets summed into a single voltage source, followed by a differential (or instrumentation) amplifier

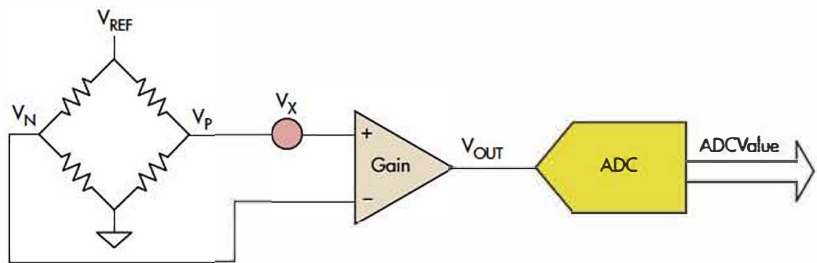
and the ADC (Fig. 1). For this system, the output voltage is:

$$V_{\text{Out}} = \text{Gain}(V_p + V_x - V_N) \quad (1)$$

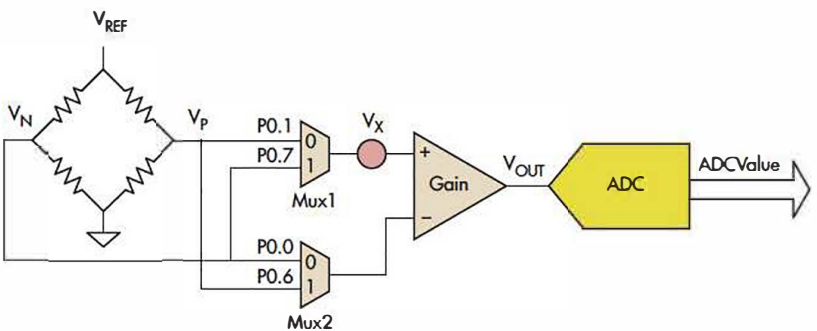
$$\text{ADC Value} = \frac{V_{\text{Out}}}{V_{\text{Ref}}} 2^n$$

where n is the bit resolution of the converter. A differential multiplexer is next added between the strain gage and the amplifier input (Fig. 2). The input pairs are reversed, but the offset voltage stays at the same place in the loop.

When Mux1 and Mux2 are set to input 0, the instrument amp and ADC outputs are:



1. The standard bridge-to-ADC model sums the offsets into a single voltage source. The signal plus offset goes through a differential/instrumentation amplifier prior to digitization.



2. The addition of a multiplexer allows for eventual cancellation of the offset voltage error by reversing the differential input signal but not the associated offset voltage.

$$V_{Out0} = \text{Gain}(V_p + V_x - V_N)$$

$$\text{ADCValue0} = \frac{\text{Gain}(V_p + V_x - V_N)}{V_{Ref}} 2^n \quad (2)$$

When Mux1 and Mux2 are set to input 1, the instrument amp and converter outputs are:

$$V_{Out1} = \text{Gain}(V_N + V_x - V_p)$$

$$\text{ADCValue0} = \frac{\text{Gain}(V_N + V_x - V_p)}{V_{Ref}} 2^n \quad (3)$$

When output 1 is subtracted from output 0 (in software), the result is:

$$\text{ADCValueDiff} = \frac{\text{Gain}(V_p + V_x - V_N - (V_N + V_x - V_p))}{V_{Ref}} 2^n$$

$$\text{ADCValueDiff} = \frac{2 * \text{Gain}(V_p - V_N)}{V_{Ref}} 2^n \quad (4)$$

As a result, the offset voltage is subtracted out, and the sensitivity is doubled. If the offset voltage drifts, it is still cancelled out. Adding a low-pass filter reduces the low-frequency noise by the ratio of the filter bandwidth to the sample rate.

The filter can be one of several: a decimating-average type using a finite impulse response (FIR), a running-average type using an FIR, or a running-average type using an infinite impulse response (IIR). The decimating average uses the least RAM, but has the slowest update rate. The running average FIR yields a clean signal but uses a lot of RAM. The IIR is more

computationally complex but yields a lot of filter roll-off for minimal amount of RAM.


Chopper-stabilized op amps are available with very low offset voltages, but they don't eliminate any offset error from the ADC. The circuit performs the functions of a chopper-stabilized amplifier—namely, high gain and very low offset. It includes the ADC as well, resulting in a low-offset system where the offset of the ADC is cancelled out at the same time as the offset of the instrumentation amplifier.

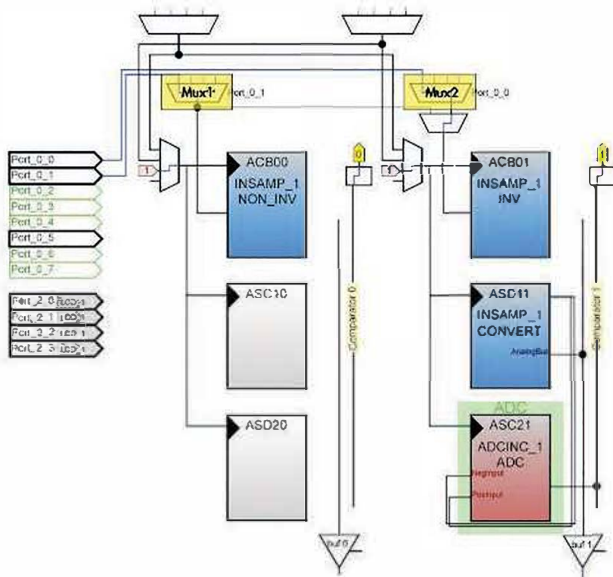
This circuit can be implemented with low-cost op amps, a multiple-channel two-input multiplexer (e.g., CD4053), a suitable ADC, and a few resistors. More easily, it drops into a Cypress PSoC1 part such as the CY8C24423, which has the multiplexers, an instrumentation amplifier, and an ADC (either an incremental or a delta-sigma). The PSoC1 design requires no external parts. PSoC's design tool, PSoC Designer, shows the implementation (Fig. 3).

The positive bridge output is connected to P0.1 for mux_1 and P0.0 for mux_2. The negative bridge output is connected to P0.7 for mux_0 and P0.0 for mux_1. The muxes are switched in software using the user modules' standard application programming interfaces (APIs). It takes about 20 lines of C code to control the muxes and get data, and a few more to display or send it. The instrumentation amplifier is brought out on P0.5 so you can see the amplified input toggling between its normal and inverting values.

To convince yourself that it works, short the inputs together at some mid-range value. Then, in software, average and stream out the V_p value (the value of the differential amplifier's input offset voltage) and the difference value. The ADCValueDiff is the offset-cancelled version.

Unless you got lucky and happened to pick up amps with super-low offset voltage, the difference will be clear. A quick test on four CY8C24423 chips showed that the instrumentation amplifier offset averaged 1.82 mV, which is well within the device spec. With the offset cancellation in place, the system offset was less than 6.0 μ V. This is an offset reduction of a factor of 300, done with cheap parts and easy connections.

This circuit also works well with PSoC3, PSoC5, and PSoC4 series parts. The differential amplifier is constructed out of back-to-back programmable gain amplifiers (PGAs) in PSoC3 and PSoC5. PSoC4 requires resistors to set the gain in the differential amplifier. The differential amplifier outputs in these designs feed a differential ADC, eliminating the need for the third op amp in an instrument amp and a single-ended ADC. 



3. With the PSoC design tool, you can set up the necessary circuit elements in the required configuration to implement the offset-cancellation scheme.

DENNIS SEGUINE IS a member of the Technical Staff at Cypress Semiconductor Corp. He has been an applications engineer for Cypress Semiconductor since 2000, following many years of analog, embedded system, and software design for the underwater, instrumentation, and medical industries.

Audio Function Generator Provides Three Simultaneous Square, Triangle, Sine Waveforms

PETRE TZVETANOV PETROV | MICROENGINEERING, SOFIA, BULGARIA ptzvp1@yahoo.fr

THIS SIMPLE, ROBUST, and low-cost signal generator, based on the LM386 power amplifier IC, provides a trio of audio-band signals with three different simultaneous outputs at the same frequency: square/rectangle (SQW), triangle (TRG), and sine (SS).

Each output can drive loads such as long cables, transformers, auto-transformers, audio couplers, or active loudspeakers. The amplitude of each output can be adjusted independently. The outputs can be connected to ground, the power supply, or between them for short time without damage.

The generator is useful for checking electrical or audio installations, audio or mains transformers, and similar components. The suggested maximum load for each output is 8 Ω, but lower-impedance loads also can be handled with some reduction in output. As a further convenience, the user can switch the output triplet between two frequencies.

The simplified block circuit shows IC1 operating as a square-wave generator with frequency determined mainly by R1 and C1 (Fig. 1). The signal in point A is approximately

triangular with amplitude of about 0.35 V p-p and a supply rail of +9 V.

The triangular signal goes to amplifier IC2 via potentiometer P1. It is also routed to the low-pass filter (LPF) or a band-pass filter (BPF). The quality of that filter determines the quality of the sinusoidal signal, which IC3 amplifies.

The 3-dB frequency of the LPF should be equal to or lower than the frequency of the triangular signal at point A. With a BPF, the central frequency or the resonant frequency should be approximately equal to that of the signal at the same point. In the simplest case, these can be second-order low-pass RC, RC band-pass, LC band-pass, or LC low-pass filters. IC3 amplifies the sinusoidal signal at point B, after potentiometer P2.

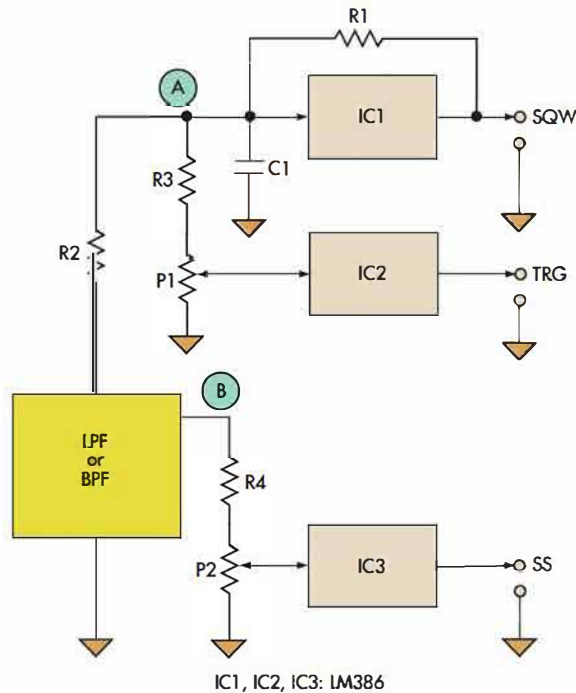
IC2 and IC3 are used with a gain of 200. This may result in trapezoidal-like signals at outputs TRG and SS when the input signals are too large and the amplifiers are saturated. If this is a problem, then the gains of IC2 and IC3 can be set to approximately 50 as described in the IC data sheet.

The actual circuit of the generator is built with three LM386 ICs. It produces two frequencies, selectable via double-pole double-throw (DPDT) switch S1 (Fig. 2). When the switch is in position 1, the frequency is 1 kHz. In position 2, it is 500 Hz. Trimmer potentiometer P1 is used to fine-adjust the nominal 1-kHz frequency, while the 500-Hz output is not adjustable, for simplicity.

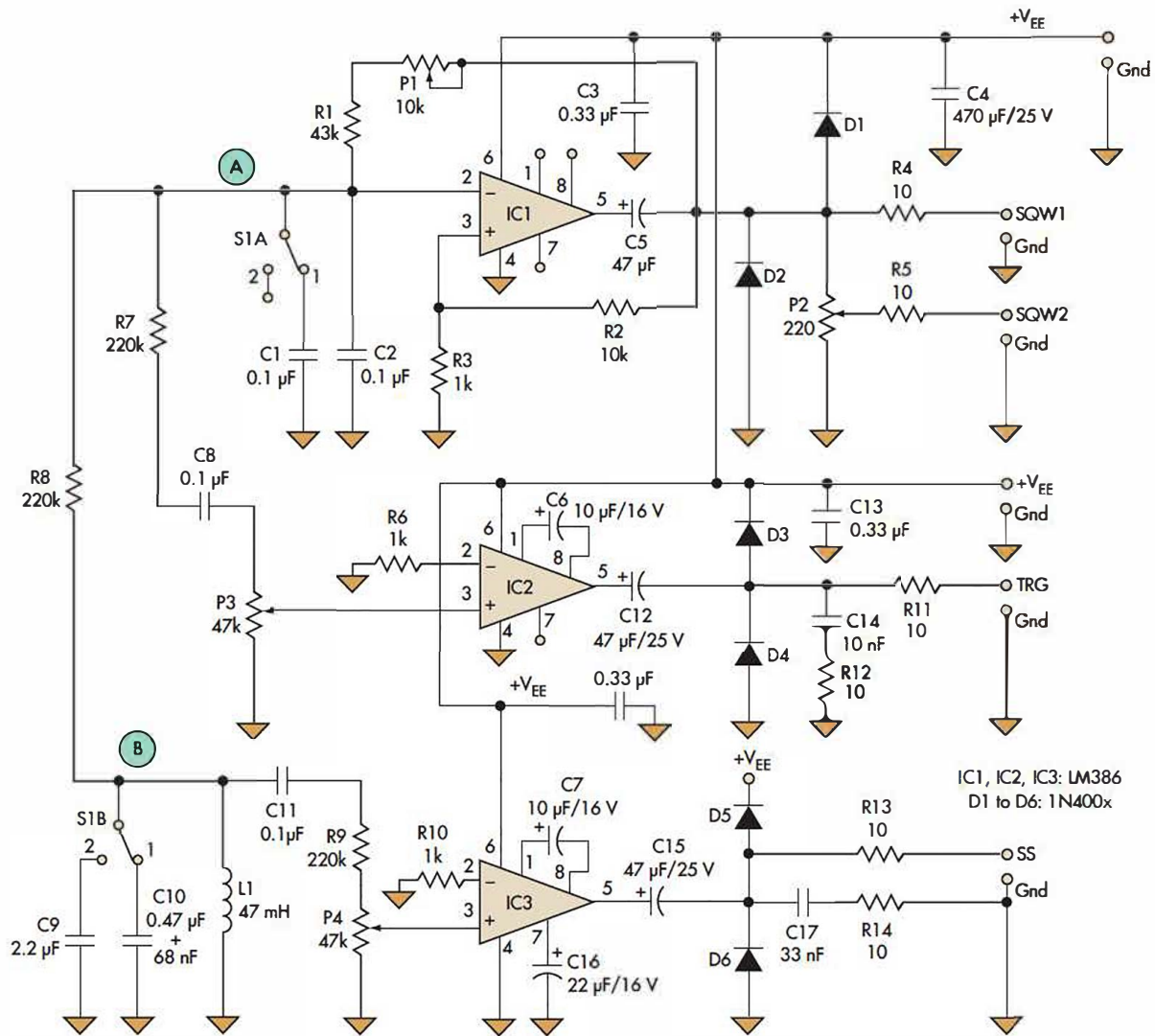
IC2 amplifies the triangular signal from point A via potentiometer P3. It also goes to the band-pass LC filter built with C9 (or C10) and L1. The resonant frequency of L1/C9 is around 500 Hz, while the resonant frequency of L1/C10 is 1 kHz, with C10 implemented as two capacitors in parallel (0.47 μF + 68 nF). The resonant frequency F of the LC tank can be approximated using the standard formula $F = 1/(2\pi\sqrt{LC})$.

Depending on the position of the wiper of the P3, output TRG will be triangular or trapezoidal, with the maximum amplitude limited by the power supply. The square-wave signal is available at the outputs SQW1 (non-adjustable amplitude) and SQW2 (adjustable amplitude with the potentiometer P2). The sinusoidal signal at point B is connected via potentiometer P4 to be amplified by IC3. The amplified signal is available as output SS.

The internal noise of the chosen LM386 may not be specified, so its gain should be minimized. The values of R1, R7, R8, R9, P3, and P4 also should be minimized to minimize



1. The block diagram shows how three low-power audio amplifiers (LM386) are configured to implement a triple-waveform generator at one of two selectable frequencies.



2. The frequency of the simultaneous square, triangle, and sine waveforms can be switched between two values (here, 500 Hz and 1 kHz) via DPDT switch S1, which selects the capacitor for the resonant LC tank.

noise. The LM386 amplifier is available from different sources with some variations in specifications, such as an operating supply range from 4 to 12 V or 5 to 18 V. Typical and maximum output power is a function of the LM386 chosen, as well as operating voltage and load impedance. 📧

PETRE TZVETANOV PETROV is an electronics engineer with Micro-Engineering, Sofia, Bulgaria. He has worked as a researcher and assistant professor at Technical University, Sofia, and has been an expert lecturer at OFPPT, Casablanca, in the Kingdom of Morocco.