TEST 18-BIT ADCs WITH AN ULTRAPURE SINE-WAVE OSCILLATOR

WITH CAREFUL DESIGN, THIS CIRCUIT CHALLENGES TEST EQUIPMENT'S ABILITY TO VERIFY ITS PERFORMANCE.

BY JIM WILLIAMS AND GUY HOOVER • LINEAR TECHNOLOGY

The ability to faithfully digitize a sine wave is a sensitive test of high-resolution-ADC fidelity. This test requires a sine-wave generator with residual distortion products approaching 1 ppm (part per million). It also requires a computer-based ADC-output monitor to read and display the converter's output spectral components. Performing this testing at reasonable cost and complexity requires the construction of its elements and performance verification before its use. A low-distortion oscillator drives the ADC through an amplifier (**Figure 1**). The ADC's output interface formats the converter output, which communicates with the computer. The computer executes spectral-analysis software and displays the resulting data.

IMAGE: ISTOCKPHOTO.COM

OSCILLATOR CIRCUITRY

The system's oscillator is the most difficult-to-design part of the circuit. The oscillator must have transcendentally low levels of impurity to meaningfully test 18-bit ADCs. You must then verify these impurity characteristics by independent means.

Start with a design based on the work of Winfield Hill, director of the electronics-engineering laboratory at the Rowland Institute at Harvard University. You can then adapt this design for a 2-kHz Wien-bridge design (**Figure 2**). Using all of the amplifiers in inverting mode eliminates CMRR (common-mode-rejection-ratio) errors from the signal path.

Low-distortion amplifiers A_1 and A_2 are the active components of this oscillator. The JFET of the original design would introduce conductivity-modulation errors, so you can replace it with an LED-driven CdS (cadmium-sulfide) photocell isolator. You then combine the output of A_2 with a filtered dc offset at the input to A_3. The capacitor in A_3's feedback network limits the bandwidth of the amplifier. The output of this 2.6-kHz filter drives the input amplifier of the ADC under test.

The A_1/A_2 oscillator needs AGC (automatic gain control), so you ac-couple the circuit's output to a high-impedance, low-noise JFET-input amplifier, A_4, which feeds precision rectifier A_5. A_5 in turn drives integrator A_6. A_6's dc output represents the ac amplitude of the circuit's output sine wave.

AT A GLANCE

- Measuring 18-bit ADCs requires a good oscillator.
- You can adapt a Wien-bridge circuit.
- A photocell performs AGC (automatic gain control) better than does a JFET.
- Be sure to verify the oscillator's circuit performance with calibrated test equipment.

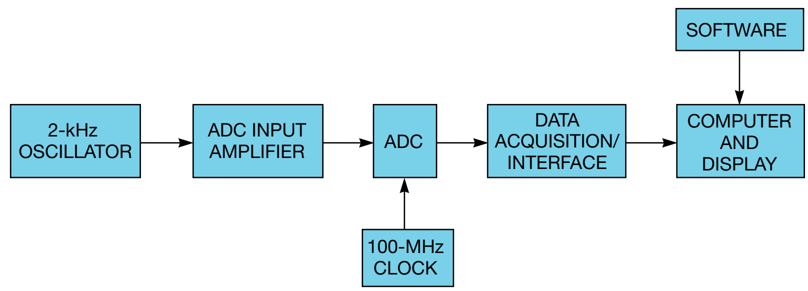

Figure 1 In a spectral-purity test system for an ADC and a distortion-free oscillator, the computer displays the Fourier components due to amplifier and ADC infidelity.

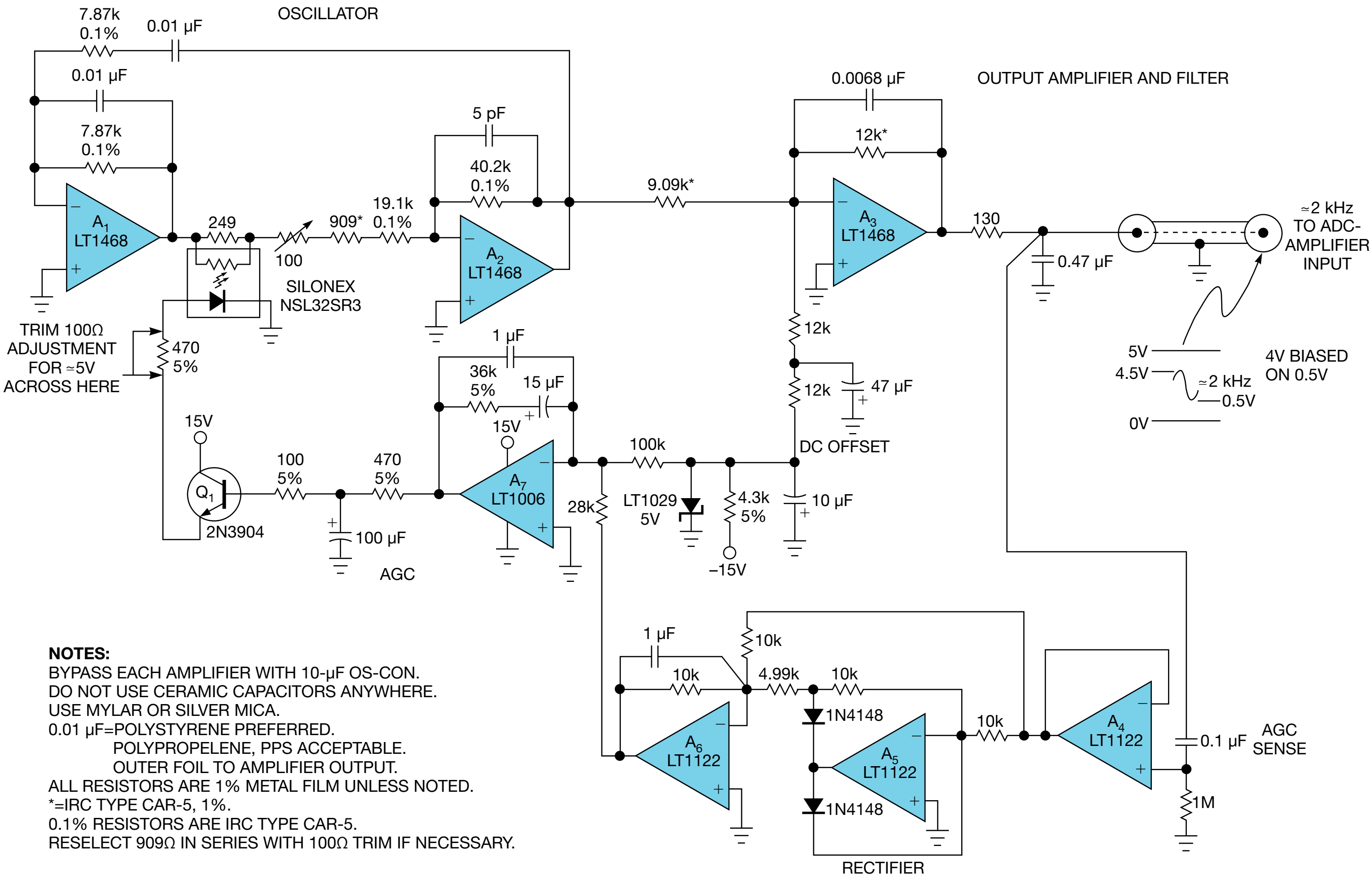

Figure 2 A Wien-bridge oscillator uses inverting amplifiers in the signal path and achieves 3-ppm distortion. An LED photocell replaces the usual JFET as gain control.

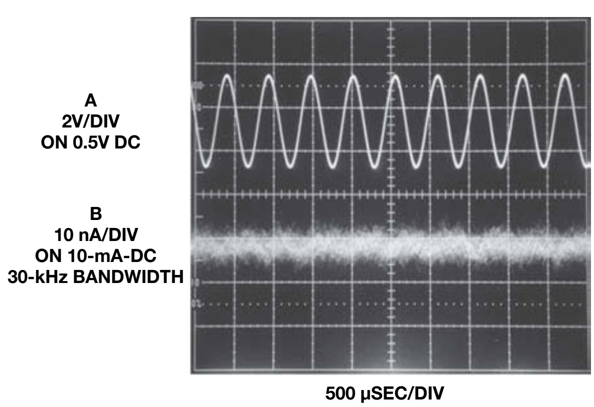

Figure 3 Trace A is the oscillator's output. Related residue (Trace B) is just discernible in Q_1's emitter noise. At approximately 1 nA, it represents 0.1 ppm of LED-current variation. Heavy AGC signal-path filtering prevents modulation products from influencing the photocell response.

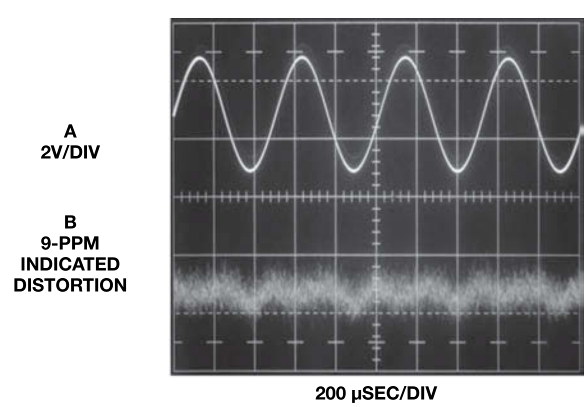

Figure 4 An HP-339A distortion analyzer operating beyond its resolution limit provides misleading distortion indication (Trace B). The analyzer output contains an unreliable combination of oscillator and instrument signatures. Trace A is the oscillator's output.

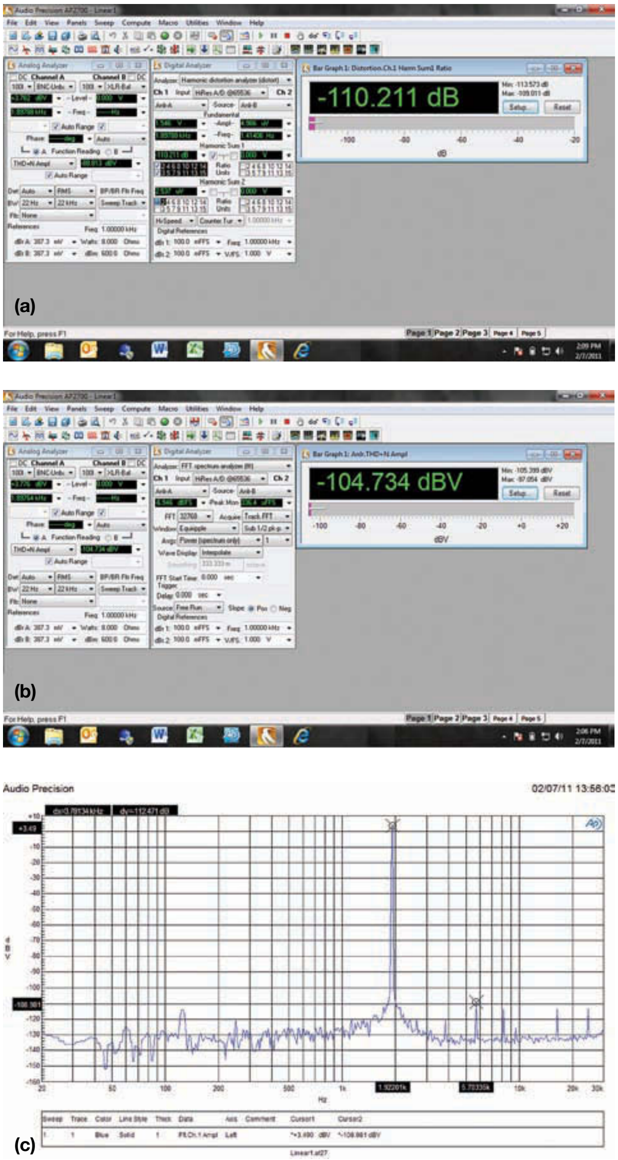

Figure 5 The Audio Precision 2722 analyzer measures oscillator THD at –110 dB, or approximately 3 ppm (a). The analyzer measures oscillator THD+N at –105 dB, or approximately 5.8 ppm (b). Its spectral output indicates a third harmonic peak at –112.5 dB, or 2.4 ppm (c).

Current-summing resistors can be used to balance the dc value against a voltage reference that the Linear Technology (www.linear.com) LT1029 IC creates. The current-summing resistors feed the AGC single-supply amplifier, A_7. This amplifier drives Q_1, which sets the LED current. The LED current closes a gain-control loop because it ultimately varies the CdS cell's resistance, stabilizing the oscillator's output amplitude.

By deriving the gain-control feedback from the circuit's output, you maintain the output amplitude, despite the attenuating, bandlimiting response of A_3 and the output filter. This topology also places demands on the loop-closure dynamics of amplifier A_7. A_3's bandlimiting, the output filter, A_6's lag, and the ripple-reduction components that attach to Q_1's base combine to generate a significant amount of phase delay. You can accommodate this delay with a 1-μF dominant pole at A_7, along with a zero-value RC (resistor/capacitor), to achieve stable loop compensation. This approach replaces closely tuned high-order output filters with simple RC roll-off responses, minimizing distortion and maintaining constant output amplitude.

It is essential that you eliminate oscillator-related signal components from the LED bias to maintain low distortion. Any such residue modulates the oscillator's amplitude, introducing impure frequency components. The bandlimited AGC signal path is well-filtered.

The heavy RC time constant in Q_1's base provides a final, steep roll-off response. Q_1's emitter current shows approximately 1 nA of oscillator-related ripple from a 10-mA total—less than 0.1 ppm (**Figure 3**). The oscillator needs only one 100Ω trim to achieve its performance. This adjustment is set in accordance with the notes in **Figure 2** and centers the AGC's capture range.

OSCILLATOR DISTORTION

Verifying oscillator distortion necessitates sophisticated measurement techniques. You will encounter limitations if you attempt to measure distortion with a conventional distortion analyzer, even a high-grade type. An oscilloscope can be used to indicate distortion residuals at the analyzer's output (**Figure 4**).The amplifier's floor faintly outlines noise and uncertainty on any signal activity that relates to the oscillator.

The Hewlett-Packard (www.hp.com) HP-339A analyzer specifies a minimum measurable distortion of 18 ppm. The **figure** shows the instrument indicating 9 ppm, which is beyond the unit's specification and, hence, highly suspicious. Measuring distortion at or near the limits of your equipment yields pronounced uncertainties. Distortion measurements at or near equipment limits are full of unpleasant surprises (**Reference 1**).

Specialized analyzers with low uncertainty floors are needed to meaningfully measure oscillator distortion. The Audio Precision (www.ap.com) 2722 analyzer has a maximum 2.5-ppm THD+N (total harmonic distortion plus noise) and a typical THD+N of 1.5 ppm. This instrument measures the oscillator's THD in three tests and finds THD figures of –110, –105, and –112 dB at 3, 5.8, and 2.4 ppm, respectively (**Figure 5**). These measurements provide confidence in applying the oscillator to ADC-fidelity characterization.

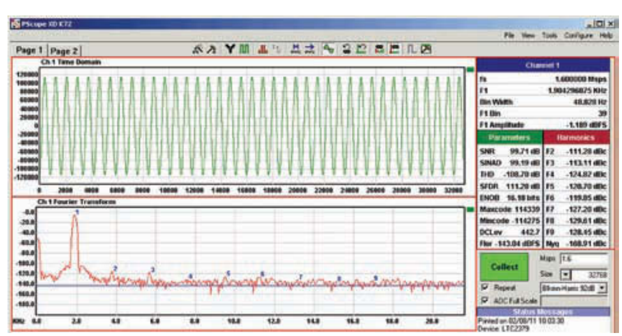

Figure 6 A partial display of the test system includes time-domain information, a Fourier spectral plot, and detailed tabular readings for an LT6350-driven ADC.

ADC TESTING

When you test ADCs, you route the oscillator's output to the ADC through its input amplifier. The test measures distortion products produced by a combination of the ADC and the ADC's input amplifier. You then examine the ADC's output with a computer, which quantitatively indicates spectral-error components (**Figure 6**).

You can download the code to take measurements and obtain input-amplifier, ADC, computer-data-acquisition, and clock boards from the Linear Technology Web site. Appropriate parts include an oscillator; the Linear Technology LT6350 amplifier; the LTC1279 ADC; the DC718 interface card; and any stable, low-phase-noise, 3.3V clock capable of driving 50Ω.

The computer display includes time-domain information showing the biased sine wave centered in the converter's operating range. It also displays detailed tabular readings and a Fourier transform indicating spectral-error components. The amplifier/ADC combination under test produces second harmonic distortion of −111 dB, which is approximately 2.8 ppm. The higher-frequency harmonics are well below this level, indicating that the ADC and its input amplifier are operating properly and within specifications. Harmonic cancellation may occur between the oscillator and amplifier/ADC combo, mandating that you test several amplifier/ADC samples to enhance your confidence in the measurement. EDN

REFERENCE

1 Williams, Jim, "Bridge Circuits: Marrying Gain and Balance," Application Note 43, Linear Technology, June 1990, http://bit.ly/pF8qsv.

AUTHORS' BIOGRAPHIES

Jim Williams was a staff scientist at Linear Technology Corp, where he specialized in analog-circuit and instrumentation design. He served in similar capacities at National Semiconductor, Arthur D Little, and the Instrumentation Laboratory at the Massachusetts Institute of Technology. He was a former student at Wayne State University (Detroit) and enjoyed sports cars, art, collecting antique scientific instruments, sculpture, and restoring old Tektronix oscilloscopes. A long-time EDN contributor, Williams died at age 63 in June 2011 after a stroke.

Guy Hoover is an applications engineer at Linear Technology Corp in the mixed-signal-products group supporting SAR (successive-approximation-register) ADCs. He has a bachelor's degree in electronics-engineering technology from DeVry Institute of Technology (San Francisco, CA). Hoover has written several application notes and articles. His hobbies include watching classic sci-fi movies and collecting high-tech gadgets.

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