# DESIGN NOTES

# Low Noise, Precision Op Amp Drives High Resolution SAR ADCs

Design Note 1039

Erjon Qirko and Kris Lokere

## Introduction

The LT6018 is an ultralow noise (1.2nV/√Hz at 1kHz) operational amplifier with ultralow distortion (–115dB at 1kHz). It has a gain bandwidth product of 15MHz, maximum offset voltage of 50μV and a maximum offset voltage drift of 0.5μV/°C. This combination of features makes it suitable for driving a variety of high resolution analog-to-digital converters (ADCs). This Design Note presents circuits and optimization strategies to achieve the best signal-to-noise ratio (SNR) and total harmonic distortion (THD) when using the LT6018 to drive high speed 18-bit and 20-bit successive approximation register (SAR) ADCs.

## Ultralinear 20-Bit ADC

Figure 1 shows a modification of the DC2135A demonstration circuit, with the LT6018 (replacing the LT1468) driving the LTC2378-20 20-bit SAR ADC. The LTC2378-20 stands out for its unrivaled 2ppm linearity performance. The best way to create a differential signal while maintaining linearity is by using the precision matched resistors in the LT5400 used on this demo board. A detailed theory of operation for the circuit shown in Figure 1 appears in Design Note 1032 (where the LT1468 drives the LTC2377-20).

To measure the circuit's linearity, an ultrapure sine wave is fed into the input, and the FFT is calculated at the output. The resulting THD measurement serves as proxy for the circuit's INL (integral non-linearity) performance. At an ADC sample rate of 800kHz, we use an input frequency of about 100Hz (slightly adjusted to ensure coherent sampling, alleviating FFT numerical limitations).



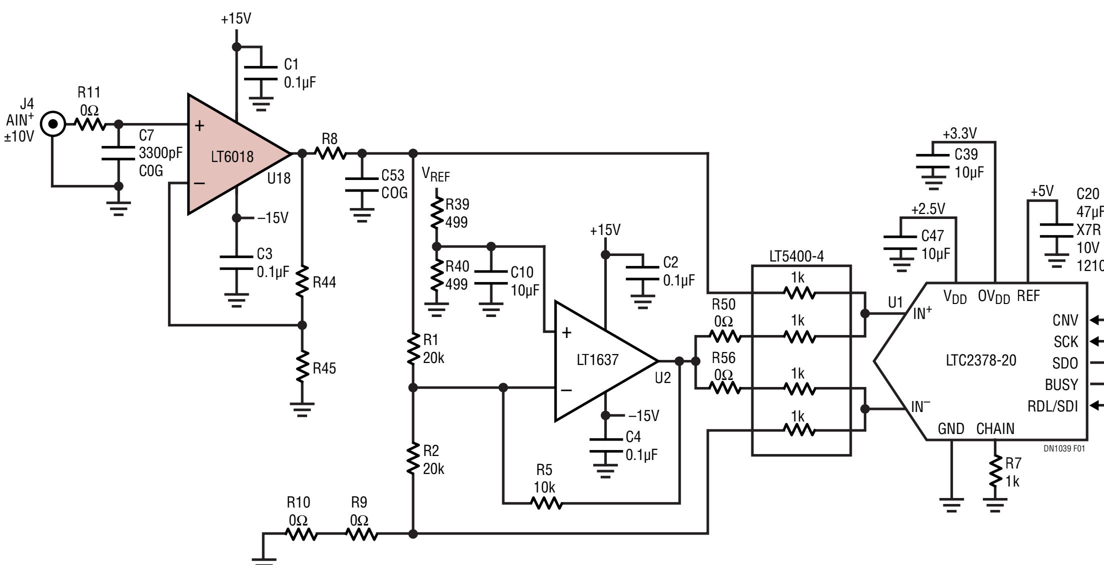


Figure 1. DC2135A Demo Board Setup

The original demonstration circuit includes an RC lowpass filter directly after the op amp to filter out excess high frequency noise. The LT6018's noise density remains relatively low even at high frequencies, so removing this filter negligibly affects total noise. Without the filter, linearity (as measured by THD) improves markedly, since the single-ended-to-differential conversion is now entirely governed by the precisely matched resistors in the LT5400, uncorrupted by any poorly matched discrete components.

The LT6018's low noise density makes it suitable for circuits that require gain. Configured in a gain of 10, the signal strength increases by 20dB while the SNR degrades by 2dB relative to full scale. If the input signals are small, this arrangement improves effective signal-to-noise ratio by 18dB. As expected, linearity is reduced by the same amount as the amplifier loop gain, or about 20dB.

The results are summarized in Table 1.

**Table 1. LT6018 Driving LTC2378-20 SNR and THD Results**

| LT6018 Gain | R8 (Ω) | C53 (µF) | R44 (Ω) | R45 (Ω) | SNR (dB) | THD (dB) |
|---|---|---|---|---|---|---|
| 1 | 10 | 0.01 | 0 | Open | 103.1 | –110.7 |
| 1 | 0 | 0 | 0 | Open | 102.5 | –121.7 |
| 10 | 14.7 | 0.0068 | 900 | 100 | 99.6 | –98.5 |
| 10 | 10 | 0.01 | 900 | 100 | 100.5 | –99.8 |

## Driving a High Speed 18-Bit ADC

The LTC2387-18 is an 18-Bit SAR ADC that can sample up to 15Msps. At this sample rate, the ADC's internal sampling capacitor is connected to the amplifier output for less than 30ns (the "acquisition time"). During that time, the amplifier (and filter) circuit must recover from charge kickback and replenish the charge of the sample capacitor, so the ADC can measure the correct input voltage at the next conversion cycle. Careful optimization of the amplifier and filter network is in order.

In Figure 2, two LT6018s are configured as unity-gain followers, and connected to the LTC2387-18 demo board, which has provisions for filter resistors and capacitors at the ADC input.

Table 2 shows the SNR and THD results, measured for a 1.008kHz pure sine wave at the input, and the ADC sampling at a coherent 14.680Msps. The first table entry shows results with the LT6200 amplifier, a very high speed, low noise op amp. The filter configuration is the demo board default bandwidth of about 200MHz. This allows full settling of the ADC charge kickback, which results in excellent THD of –120dB. However, SNR is 2dB below the 96dB capability of the ADC.

The LT6018 has lower bandwidth than the LT6200, but much better DC accuracy (offset and drift). However, plugging the LT6018 into the same configuration as the LT6200 significantly degrades SNR and THD. SNR is degraded because amplifier noise density can be

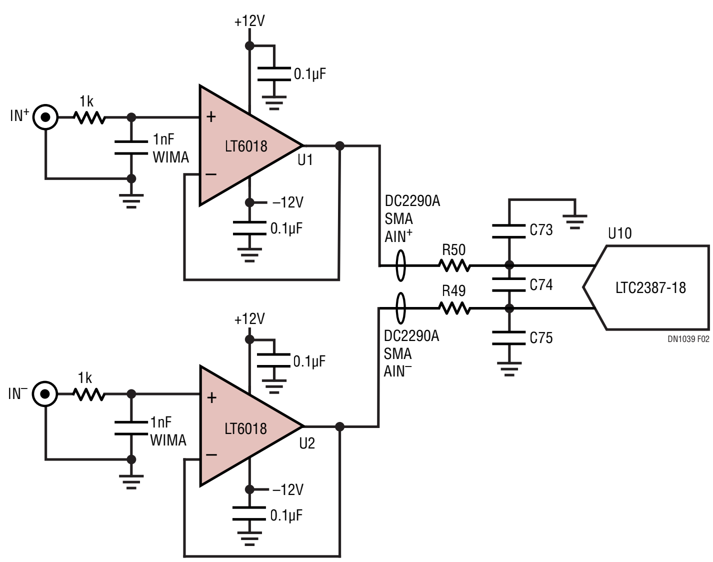


**Figure 2. The LT6018 Driving the LTC2387-18 Using the DC2290A-A Demo Board**

higher above its bandwidth than below, and this noise, if not filtered, will alias into the ADC. THD is degraded because the slower amplifier—when hit with the full ADC charge kickback—does not properly settle and leaves non-linear residues for the ADC to digitize.

We can filter the wideband amplifier noise by increasing the value of the resistors and capacitors, and by including a differential capacitor between the two ADC inputs. Doing so improves the SNR all the way to the theoretical maximum of 96dB for this ADC, which means that integrated amplifier noise has become negligible. Furthermore, by skewing the filter configuration toward smaller series resistors and larger capacitors, the initial effect of the charge kickback is attenuated, resulting in improved THD performance, well below –100dB.

**Table 2. LT6018 Driving LTC2387-18 SNR and THD Results**

| Amplifier | R49 = R50 (Ω) | C73 = C75 | C74 | SNR (dB) | THD (dB) |
|---|---|---|---|---|---|
| LT6200 | 10 | 82pF | Open | 94.2 | –120 |
| LT6018 | 10 | 82pF | Open | 90.3 | –72.9 |
| LT6018 | 25 | 1nF | Open | 94.5 | –93.7 |
| LT6018 | 25 | 1nF | 1nF | 96.0 | –96.1 |
| LT6018 | 13.7 | 1.8nF | 1.8nF | 95.9 | –101.1 |

## Conclusion

Modern SAR ADCs combine low noise with high linearity and precise DC offset accuracy. Realizing these specs requires an amplifier with similarly good DC specs, low noise and sufficient bandwidth, such as the LT6018. With moderate speed ADCs (such as the 1Msps 20-bit LTC2378-20), the LT6018, in combination with precisely matched LT5400 resistors, can create a differential input signal with no additional filtering required. With ultrafast SAR ADCs (such as the 18-bit 15Msps LTC2387-18), careful optimization of an RC filter network between the op amp and ADC results in excellent noise and linearity performance.

**Data Sheet Download**

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call (978) 656-3757

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408) 432-1900 • FAX: (408) 434-0507 • www.linear.com

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