Low Noise, Precision Op Amp Drives High Resolution SAR ADCs

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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 article 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 with the precision matched resistors in the LT®5400 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).

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

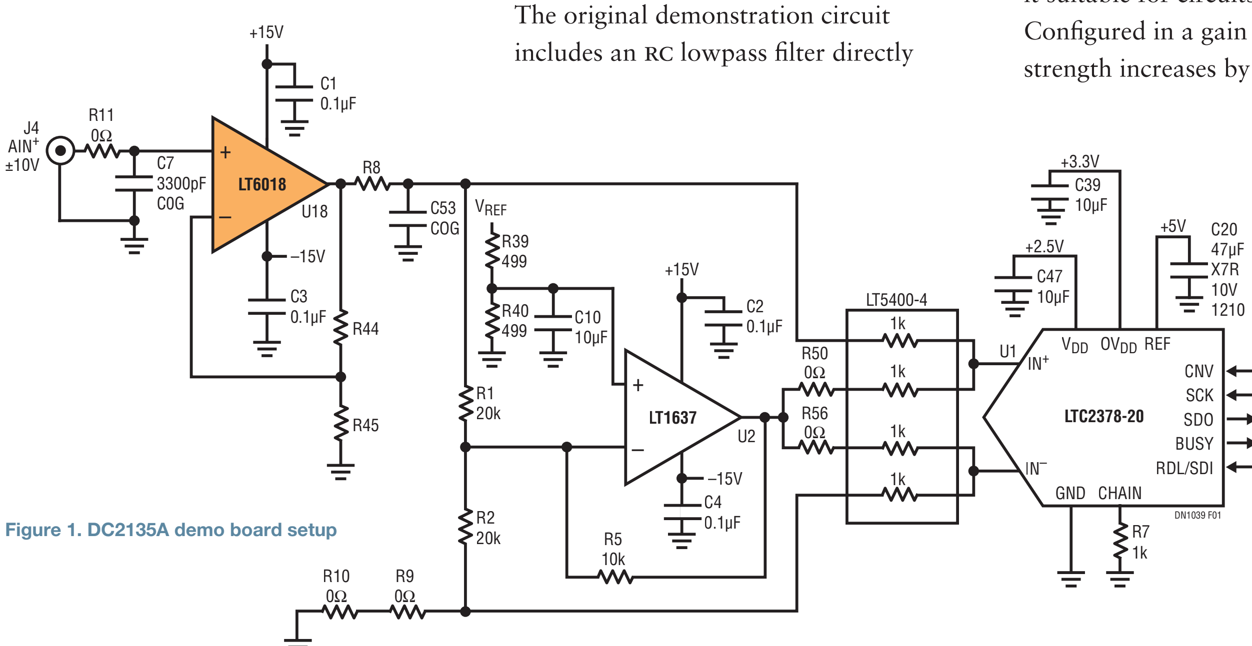

Figure 1. DC2135A demo board setup

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

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

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.

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 ("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 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.

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. ■

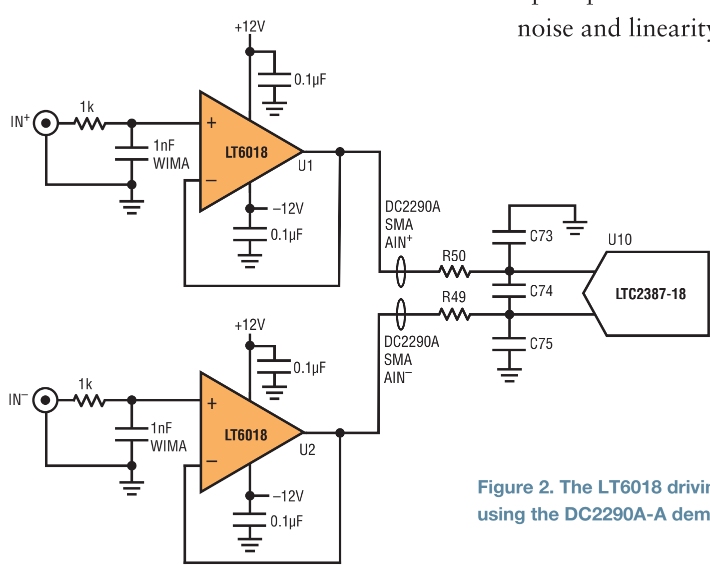

Figure 2. The LT6018 driving the LTC2387-18 using the DC2290A-A demo board