

The Refulator: The Capabilities of a 200 mA Precision Voltage Reference

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Precision analog designers often lean on the quietly humble voltage reference to power their DAC and ADC converters. This job lies outside the fundamental purview of a reference—ostensibly designed to provide a clean, precise stable voltage to an actual power source; namely a power converter's reference input. With some caveats, references are usually up to the task of providing precise voltage to the converter's reference input, emboldening designers to ask references to power increasingly higher current applications. After all, if the reference can power the converter, why not the analog signal chain, or another converter, and on down the list?

The choice between precision and power comes up often in any design process. The brute force approach to making this decision suggests using a reference when precision is demanded, and an LDO when milliwatts of power are required. Besides the additional board space and cost, separate signals must be routed, even if their nominal voltages are the same. And if a high precision voltage source is required to provide milliwatts of power, the designer is forced to buffer a reference. The **LT6658** solves this dilemma by providing two low noise precision outputs with a combined 200 mA output current and world-class reference specifications.

About the LT6658 Reference Quality Low Drift Regulator

The LT6658 is a precision low noise, low drift regulator featuring the accuracy specifications of a dedicated reference and the power capability of a linear regulator—combining the traits of both into ADI's Refulator™ technology. The LT6658 boasts 10 ppm/°C drift and 0.05% initial accuracy, with two outputs that can support 150 mA and 50 mA, respectively, each with 20 mA active sinking capability. To maintain accuracy, load regulation is 0.1 ppm/mA. Line regulation is typically 1.4 ppm/V when the input voltage supply pins are tied together and less than 0.1 ppm/V when the input pins are provided with independent supplies.

To better grasp the LT6658's features and how it achieves its level of performance, a typical application is shown in Figure 1. The LT6658 consists of a band gap stage, a noise reduction stage, and two output

buffers. The band gap and two output buffers are powered separately to provide exceptional isolation. Each output buffer has a Kelvin sense feedback pin for optimum load regulation.

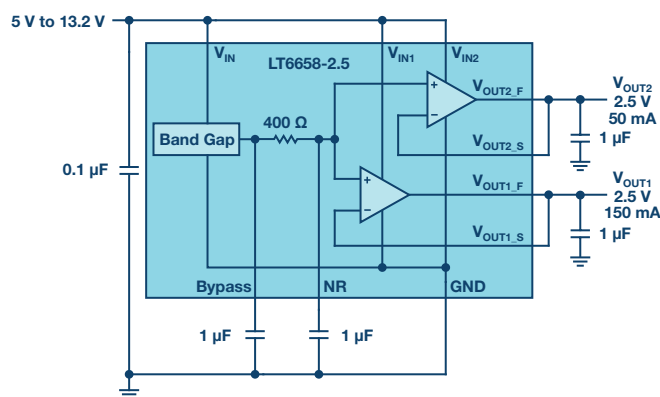


Figure 1. Typical application.

The noise reduction stage consists of a 400 Ω resistor with a pin provided for an external capacitor. The RC network acts as a low-pass filter, bandlimiting the noise from the band gap stage. The external capacitor can be arbitrarily large, reducing the noise bandwidth to a very low frequency.

Fast and Quiet Response to Load Steps

As a regulator, the LT6658 supplies 150 mA from the V_{OUT1_F} pin with excellent transient response. Figure 2a shows the response to a 1 mA load step transient from 10 mA to 11 mA; Figure 2b shows the response to a 140 mA load step from 10 mA to 150 mA. The source and sink capability of the output buffer enables fast settling of the output. The transient response is short, while excellent load regulation is maintained. Load regulation is typically only 0.1 ppm/mA. The second output, V_{OUT2_F} , has a similar response with a 50 mA maximum load.

Power Supply Rejection and Isolation

To facilitate exceptional power supply rejection and output isolation, the LT6658 provides three power supply pins. The V_{IN} pin supplies power to the band gap circuit while V_{IN1} and V_{IN2} supply power to V_{OUT1} and V_{OUT2} , respectively. The simplest approach is to connect all three supply pins together, delivering a typical dc power supply rejection of 1.4 ppm/V. When the power supply pins are connected separately and the V_{IN1} supply is toggled, the dc line regulation for V_{OUT2} is 0.06 ppm/V.

Table 1 summarizes power supply rejection as each of the power supply pins are changed from 5 V to 36 V. The V_{IN} supply has the most sensitivity, causing a typical 1.4 ppm/V change on the outputs. Supply pins V_{IN1} and V_{IN2} have almost no effect. The measurements in the V_{IN1} and V_{IN2} columns are at the level of the output noise.

Table 1. DC Power Supply Rejection

Step Supply	V (5 V to 36 V)	V_{IN1} (5 V to 36 V)	V_{IN} (5 V to 36 V)	$V_{IN} = V_{IN1} = V_{IN2}$ (5 V to 36 V)	Units
Bypass	0.01	0.02	1.36	1.36	ppm/V
V_{OUT1}	0.07	0.01	1.34	1.43	ppm/V
V_{OUT2}	0.03	0.06	1.39	1.37	ppm/V

Two examples of ac PSRR are shown in Figure 4. The first example has a 1 μ F capacitor on the NR pin while the second example includes a 10 μ F capacitor on the NR pin. The larger 10 μ F capacitor extends the 107 dB rejection to 2 kHz.

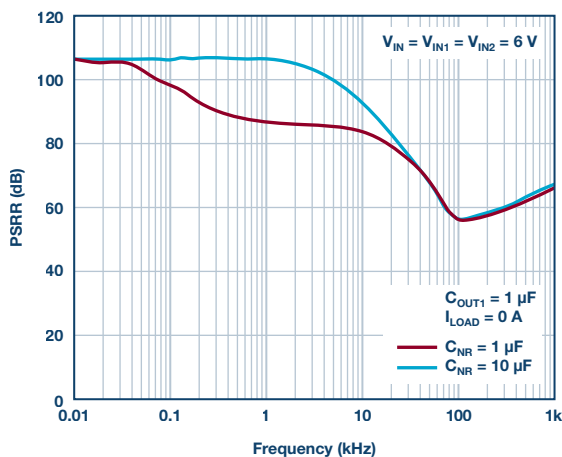


Figure 4. Power supply ripple rejection.

The ac channel-to-channel power supply isolation from V_{IN1} to V_{OUT2} is shown in Figure 5. Here the channel-to-channel power supply isolation is greater than 70 dB beyond 100 kHz when $C_{NR} = 10$ μ F.

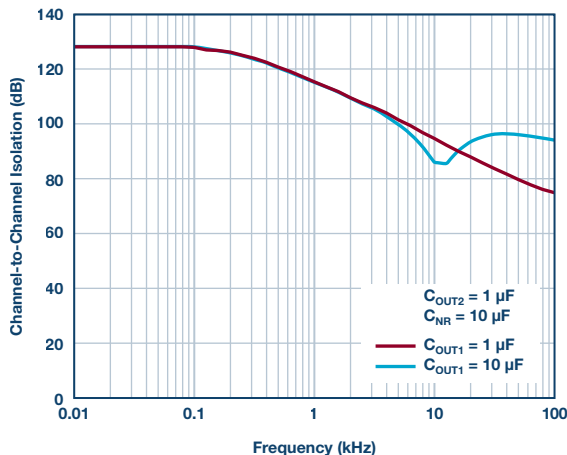


Figure 5. Channel-to-channel V_{OUT1} to V_{OUT2} isolation.

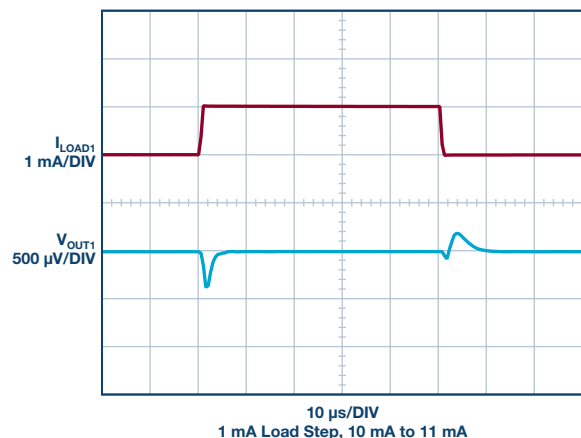


Figure 2a. 1 mA load step response..

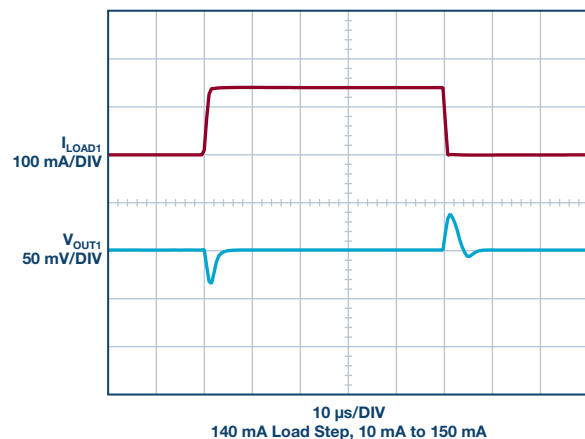


Figure 2b. 140 mA load step response.

Output Tracking

For applications with multiple converters using different voltage references, the LT6658 outputs track, even if the outputs are set to different voltages—ensuring consistent conversion results. This is possible because the two outputs of the LT6658 are driven from a common voltage source. The output buffers are trimmed, resulting in excellent tracking and low drift. As the load on V_{OUT1} increases from 0 mA to 150 mA, the V_{OUT2} output changes less than 12 ppm as shown in Figure 3. That is, the relationship between the outputs is well maintained even over varying load and operating conditions.

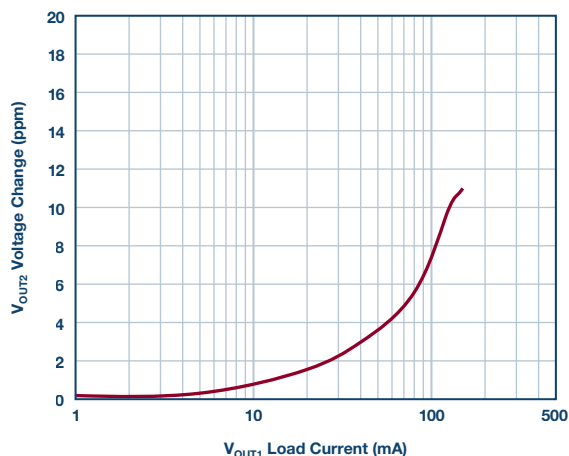


Figure 3. Channel-to-channel load regulation (effect of heating removed).

Load transients have a minimal effect on the adjacent output. Figure 6a and Figure 6b illustrate channel-to-channel output isolation. One output is wiggled at 50 mV rms, and the change in in the other is plotted.

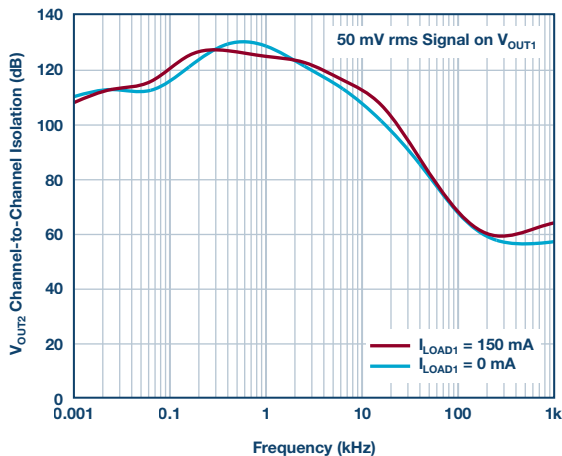


Figure 6a. Channel-to-channel V_{OUT1} to V_{OUT2} load isolation.

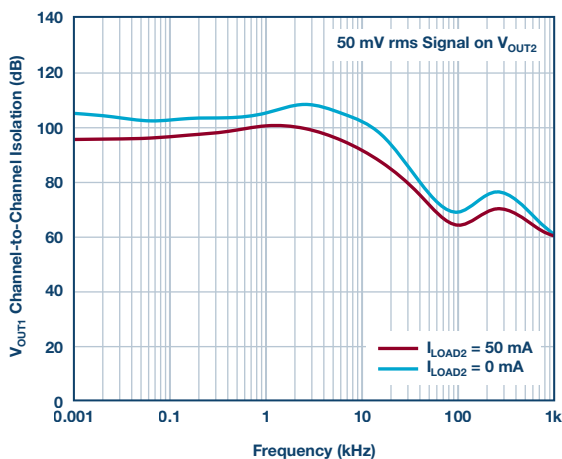


Figure 6b. Channel-to-channel V_{OUT2} to V_{OUT1} load isolation.

Extraordinary ac PSRR can be achieved using the circuit shown in Figure 7. The V_{OUT1} output bootstraps the supplies V_{IN} and V_{IN2} , resulting in a recursive reference.

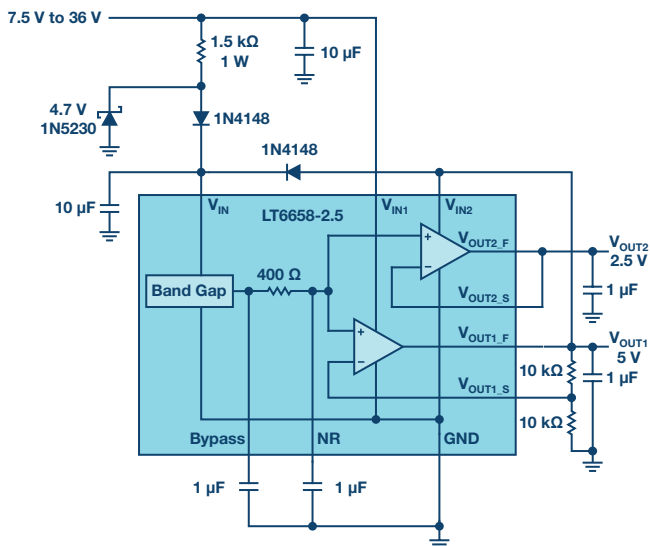


Figure 7a. Recursive reference solution (V_{OUT1} supplies power to V_{IN} and V_{IN2}).

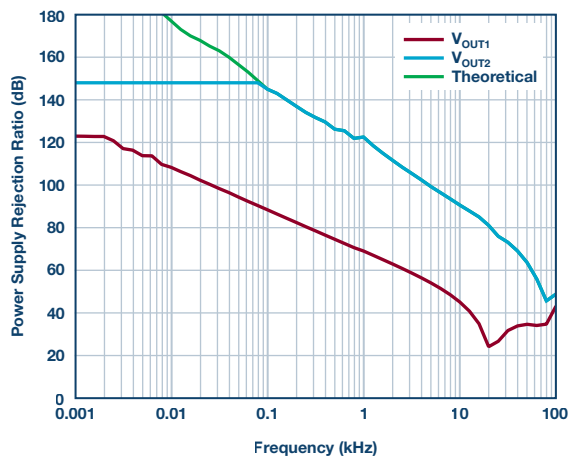


Figure 7b. AC PSSR for the recursive reference circuit.

Power Management and Protection

The three supply pins help manage the amount of power dissipated in the package. When supplying a large current, lower the supply voltage to minimize the power dissipation in the LT6658. Less voltage will appear across the output device, resulting in less power consumption and higher efficiency.

Output disable pin OD turns off the output buffers and places the V_{OUT_F} pins in a high impedance state. This is useful in the event of a fault condition. For example, a load may become damaged and shorted. This event can be sensed by external circuitry and both outputs can be disabled. This feature can be ignored and a weak pull-up current will enable the output buffers when the OD pin floats or is tied high.

The LT6658 comes in a 16-lead MSE exposed pad package with a θ_{JA} as low as 35°C/W. When the supply voltage is high, power efficiency is low, resulting in excessive heat in the package. For example, a 32.5 V supply voltage at full load produces $30\text{ V} \times 0.2\text{ A}$ of excess power across the output devices. Six watts of excess power would raise the internal die temperature to a dangerous 210°C above ambient. To protect the part, a thermal shutdown circuit disables the output buffers when the die temperature exceeds 165°C.

Noise

For data converter and other precision applications, noise is an important consideration. The low noise LT6658 can be made even lower with the addition of a capacitor on the NR (noise reduction) pin. A capacitor on the NR pin forms a low-pass filter with an on-chip 400 Ω resistor. A large capacitor lowers the filter frequency and subsequently, the total integrated noise. Figure 8 shows the effect of increasing the values of the capacitor on the NR pin. With a 10 μF capacitor, the noise rolls off to about 7 $\text{nV}/\sqrt{\text{Hz}}$.

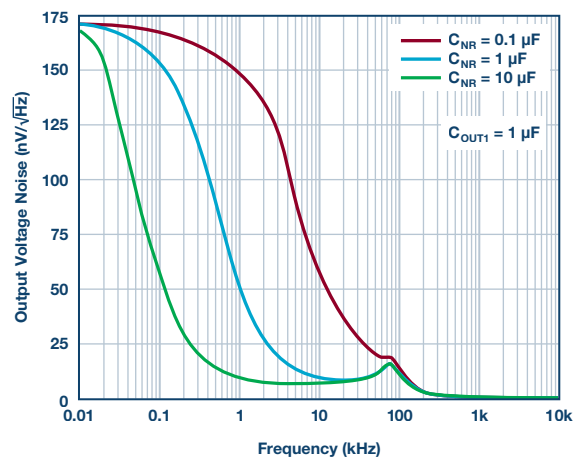


Figure 8. Noise reduction by increasing C_{NR} .

By increasing the output capacitor, the noise can be further reduced. When both the NR and output capacitors are increased, the output noise can be reduced down to a few microvolts. The LT6658 is stable with output capacitance between 1 μF and 50 μF . The output is also stable with large capacitance if a 1 μF ceramic capacitor is placed in parallel. For example, Figure 9a shows a circuit with 1 μF ceramic capacitor in parallel with a 100 μF polyaluminum capacitor. This configuration remains stable while lowering the noise bandwidth. Figure 9b illustrates the noise response for different values of output capacitance. In all three cases, there is a small 1 μF ceramic capacitor in parallel with the larger capacitor.

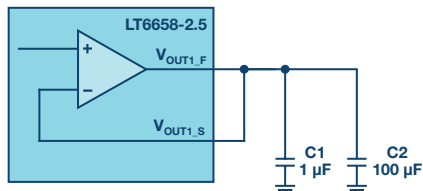


Figure 9a. Noise reduction by increasing C1.

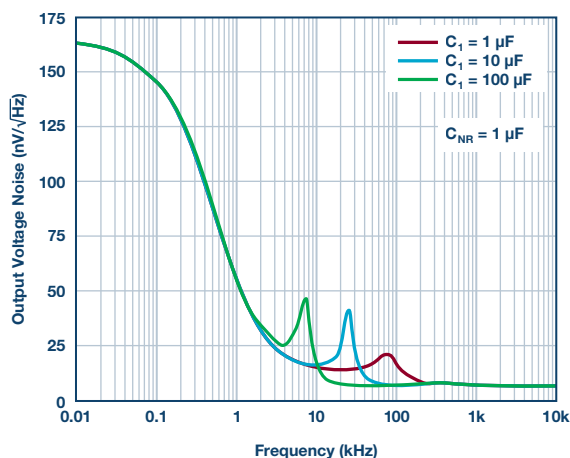


Figure 9b. Noise reduction by increasing C1.

One drawback of this scheme is the noise peaking, which can add to the total integrated noise. To reduce the noise peaking, a 1 Ω resistor can be inserted in series with the large output capacitor as shown in Figure 10a. The output voltage noise and total integrated noise are shown in Figures 10b and 10c, respectively.

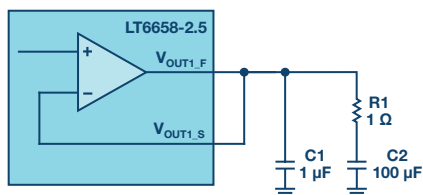


Figure 10a. Reduce noise peaking by adding a 1 Ω resistor in series with C2.

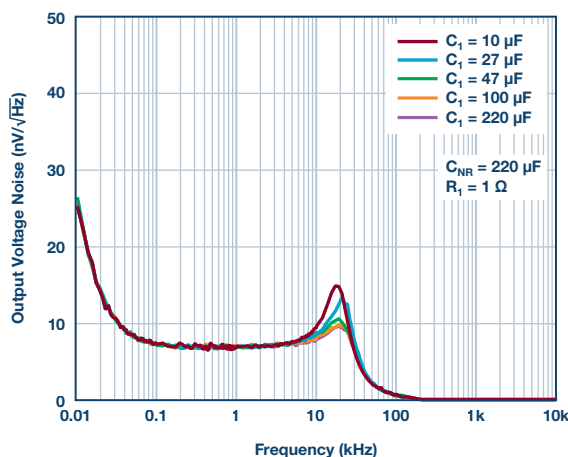


Figure 10b. Reduce noise peaking by adding a 1 Ω resistor in series with C2.

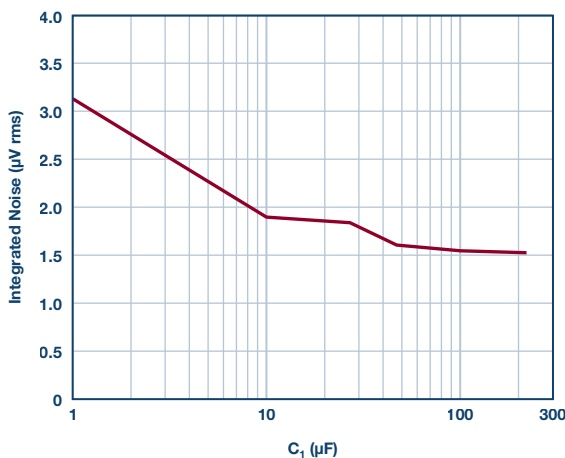


Figure 10c. Reduce noise peaking by adding a 1 Ω resistor in series with C2.

Applications

The LT6658 provides quiet, precise power for a number of demanding applications. In the mixed-signal world, data converters are often controlled by microcontrollers or FPGAs. Figure 11 illustrates the general concept. Sensors provide signals to analog processing circuits and converters, all of which need clean power supplies. The microcontroller may have several supply inputs including analog power.

As a general rule, noisy digital supply voltages for the microcontroller should be isolated from the clean, precise analog supply and reference. The two outputs of the LT6658 provide excellent channel-to-channel isolation, power supply rejection, and supply current capability, ensuring clean power to multiple sensitive analog circuits.

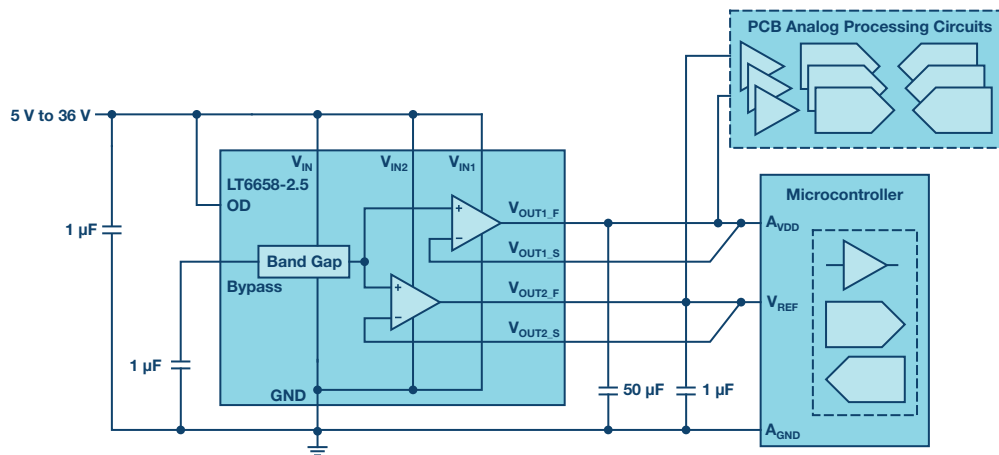


Figure 11. Mixed-signal application.

The LT6658 is also well suited to industrial environments since it can operate with noisy supply rails and where load glitches due to conversions on one output have little influence on the adjacent output. Moreover, when a load demands current on one output, the adjacent output continues to track.

A real-world example is shown in Figure 12, where the LTC2379-18 high speed ADC circuit is operated with an LT6658. The Kelvin sense input on V_{OUT2} is configured to gain up the 2.5 V output to a 4.096 V reference voltage and to provide a common-mode voltage to the input amplifier, LTC6362. V_{OUT1} is gained up to 5 V, providing power to the LTC6362 and other analog circuits that require a 5 V rail. Both LT6658 outputs have the maximum load at 150 mA and 50 mA on V_{OUT1} and V_{OUT2} , respectively.

Table 2. Data Acquisition Circuit Example from Figure 12

Parameter	16-Bit SAR	18-Bit SAR
SNR	92.7 dB	97.5 dB
SINAD	92.1 dB	95.9 dB
THD	-101.2 dB	-101.1 dB
SFDR	101.6 dB	103.2 dB
ENOB	15.01 bits	15.64 bits

The circuit in Figure 13 illustrates how the LT6658 can power noisy digital circuits while maintaining a quiet, precise reference voltage for a precision ADC. In this application, the LT6658 or a separate LDO supplies a 3.3 V rail to a noisy FPGA supply (VCCIO) and some miscellaneous logic on one channel, and 5 V to the reference input of the 20-bit ADC on the other channel.

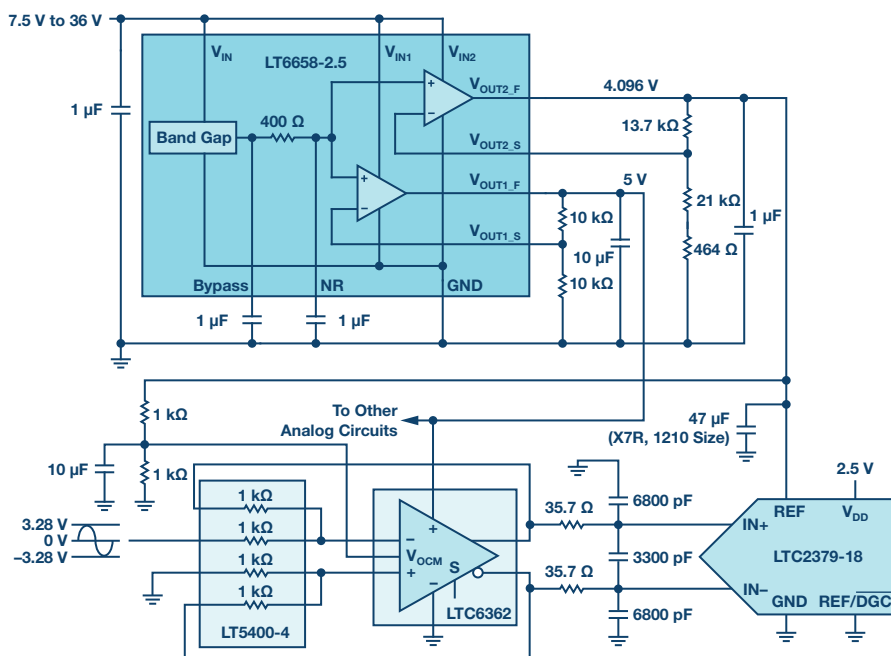


Figure 12. Data acquisition solution.

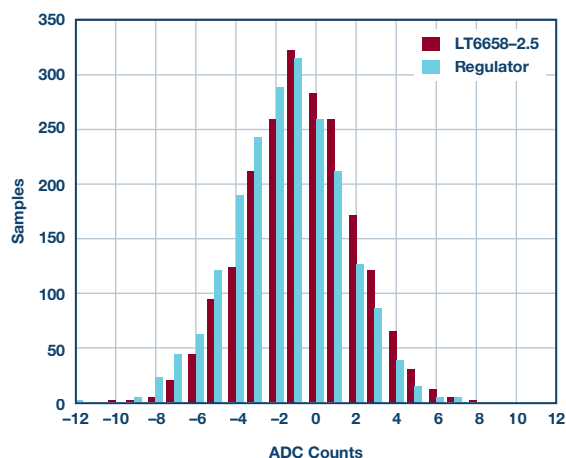


Figure 14. Histogram test results of the circuit in Figure 13.

By switching the digital supply between the LT6658 and the LDO, we can assess how well the LT6658 isolates digital noise on one channel from the channel driving the quiet reference input of the 20-bit ADC. Using a clean dc source on the input of the ADC, the noise can be inferred as shown in Figure 14. The histogram shows no appreciable difference in results between the LT6658 or the LDO supplying power to the VCCIO pins of the FPGA, demonstrating the LT6658's robust regulation and isolation.

Conclusion

The LT6658 is the next step in the evolution of references and regulators. The precision performance and ability to provide a combined 200 mA of current from a single package is a paradigm shift for precision analog power. Noise rejection, channel-to-channel isolation, tracking, and load regulation make this product ideal for precision analog reference and power solutions. With this new approach, applications do not need to compromise precision or power.

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