The Refulator: Precision Voltage Reference is an Accurate Low Noise Regulator for 200mA Loads

Michael B. Anderson

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, 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 200mA 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. The LT6658 boasts 10ppm/°C drift and 0.05% initial accuracy, with two outputs that can support 150mA and 50mA, respectively, each with 20mA active sinking capability. To maintain accuracy, load regulation is 0.1ppm/mA. Line regulation is typically 1.4ppm/V when the input voltage supply pins are tied together and

Figure 1. Typical application

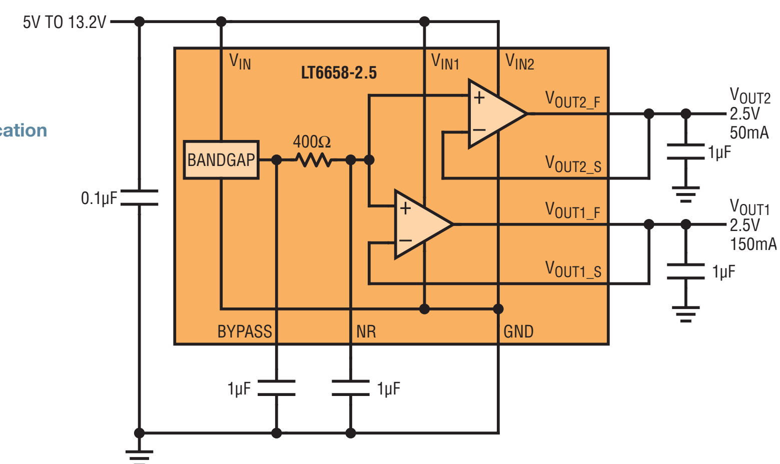
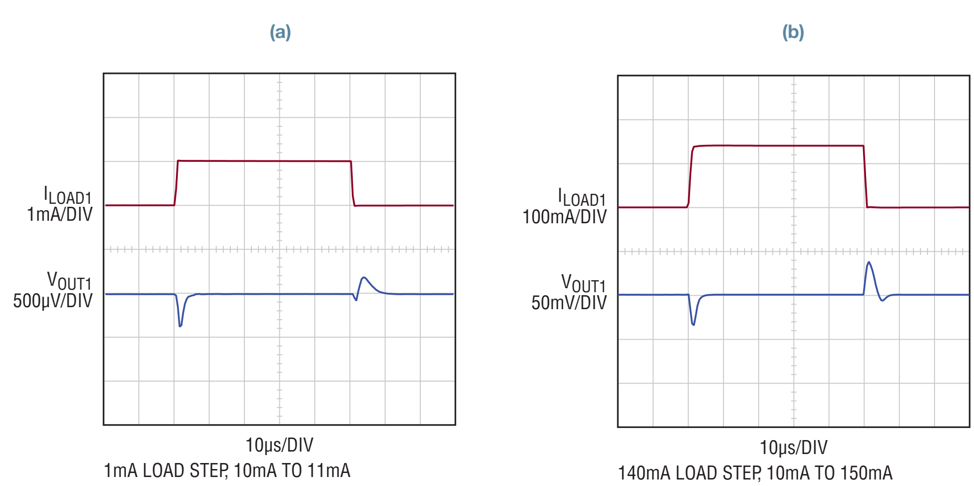


Figure 2. Load step response. (a) 1mA load step (b) 140mA load step



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less than 0.1ppm/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 bandgap stage, a noise reduction stage and two output buffers. The bandgap and two output buffers are powered separately to provide exceptional isolation. Each output buffer has a Kelvin sense feedback pin for optimum load regulation.

The noise reduction stage consists of a 400Ω resistor with a pin provided for an external capacitor. The RC network acts as a low pass filter, bandlimiting the noise from the bandgap 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 150mA from the V_{OUT1_F} pin with excellent transient response. Figure 2a shows the response to a 1mA load step transient from 10mA to 11mA; Figure 2b shows the response to a 140mA load step from 10mA to 150mA. 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 0.1ppm/mA. The second output, V_{OUT2_F}, has a similar response with a 50mA maximum load.

STEP SUPPLY	V_{IN2} (5V-36V)	V_{IN1} (5V-36V)	V_{IN} (5V-36V)	$V_{IN}=V_{IN1}=V_{IN2}$ (5V-36V)	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

Table 1. DC power supply rejection

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_F} increases from 0mA to 150mA, the V_{OUT2} output changes less than 12ppm as shown in Figure 3. That is, the relationship between the outputs is well maintained even over varying load and operating conditions.

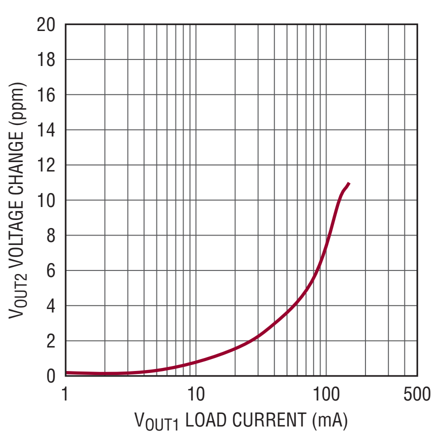


Figure 3. Channel-to-channel load regulation (effect of heating removed)

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 bandgap 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 1.4ppm/V. When the power supply pins are connected separately and the V_{IN1} supply is toggled, the DC line regulation for V_{OUT2} is 0.06ppm/V.

Table 1 summarizes power supply rejection as each of the power supply pins are changed from 5V to 36V. The V_{IN} supply has the most sensitivity, causing a typical 1.4ppm/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.

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

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.

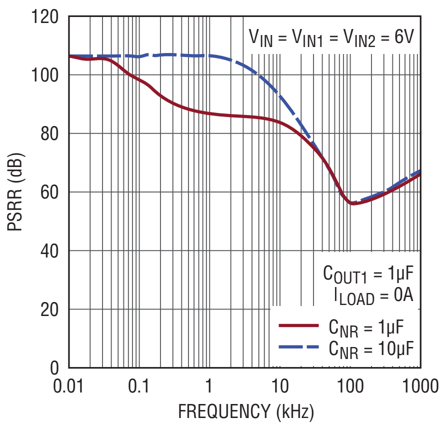


Figure 4. Power supply ripple rejection

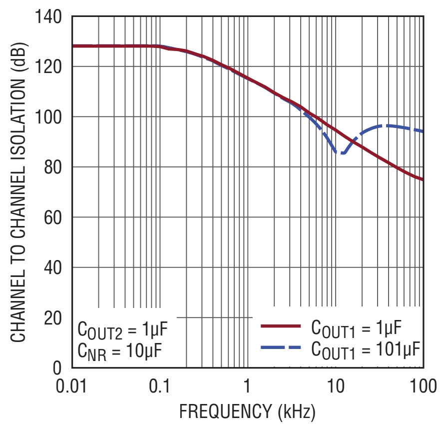


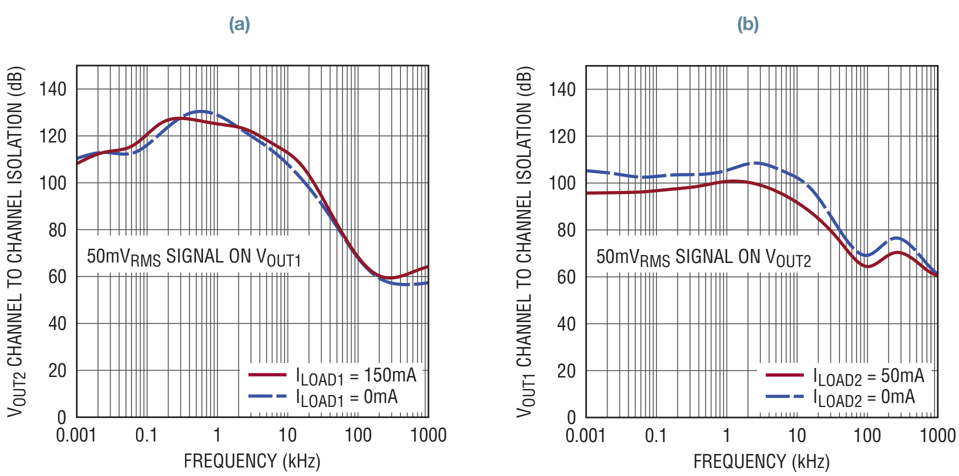
Figure 5. Channel-to-channel V_{OUT1} to V_{OUT2} isolation

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 70dB beyond 100kHz when C_{NR} = 10µF.

Load transients have a minimal effect on the adjacent output. Figures 6a and 6b illustrate channel-to-channel output isolation. One output is wiggled at $50mV_{RMS}$, and the change in in the other is plotted.

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 6. (a) Channel-to-channel V_{OUT1} to V_{OUT2} load isolation. (b) Channel-to-channel V_{OUT2} to V_{OUT1} load isolation.



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.

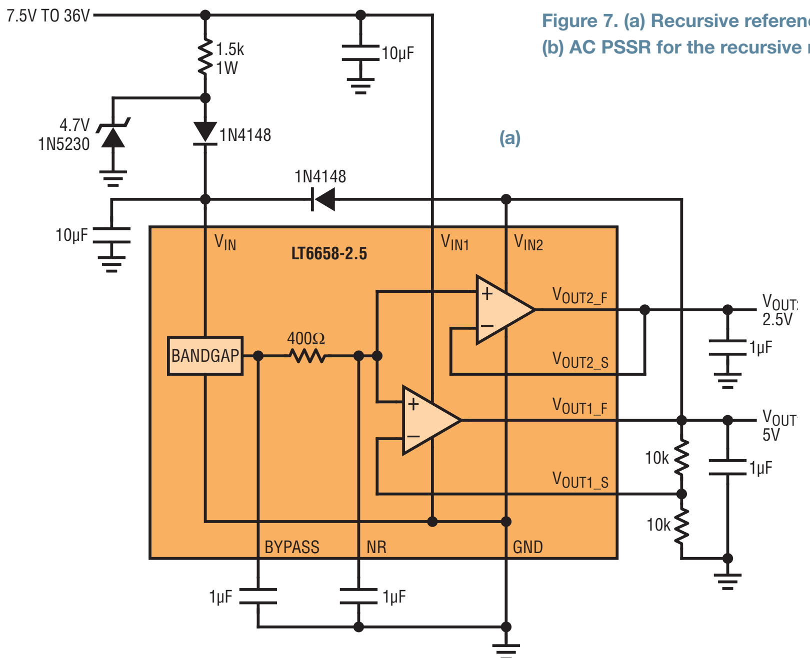
An output disable pin, OD, turns off the output buffers and places the V_{OUT_F} pins in a high impedance state. This is useful in the event of a fault condition. For example, a load may become damaged and shorted. This event can be sensed by external circuitry and both outputs can be disabled. This 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 MSE-16 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 32.5V supply voltage at full load produces 30V • 0.2A 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.

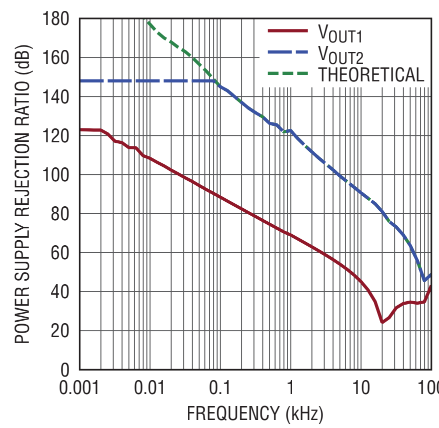
For data converter and other precision applications, noise is an important consideration. The low noise LT6658 can be made even lower with the addition of a capacitor on the NR (noise reduction) pin.

Figure 7. (a) Recursive reference solution (V_{OUT1} supplies power to V_{IN} and V_{IN2}) (b) AC PSSR for the recursive reference circuit

(a)



(b)



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 400Ω 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 10µF capacitor the noise rolls off to about $7nV/\sqrt{Hz}$.

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 1µF and 50µF. The output is also stable with large capacitance if a 1µF ceramic capacitor is placed in parallel. For example, Figure 9a shows a circuit with 1µF ceramic capacitor in parallel with a 100µF poly-aluminum capacitor.

Figure 8. Noise reduction by increasing CNR

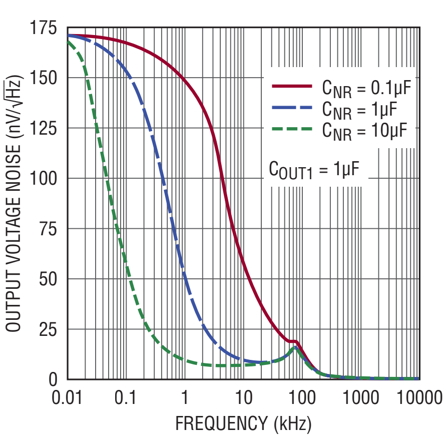
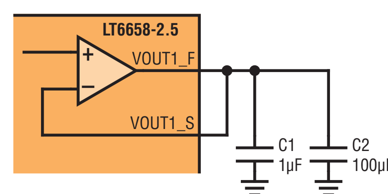
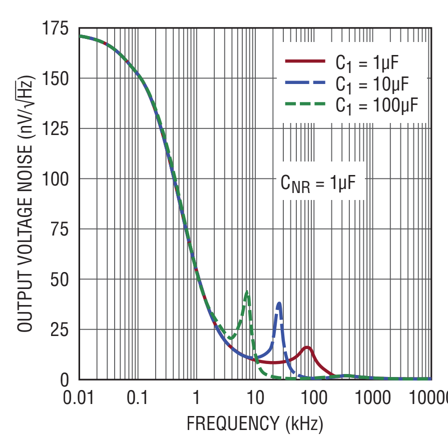


Figure 9. Noise reduction by increasing C1.

(a)



(b)



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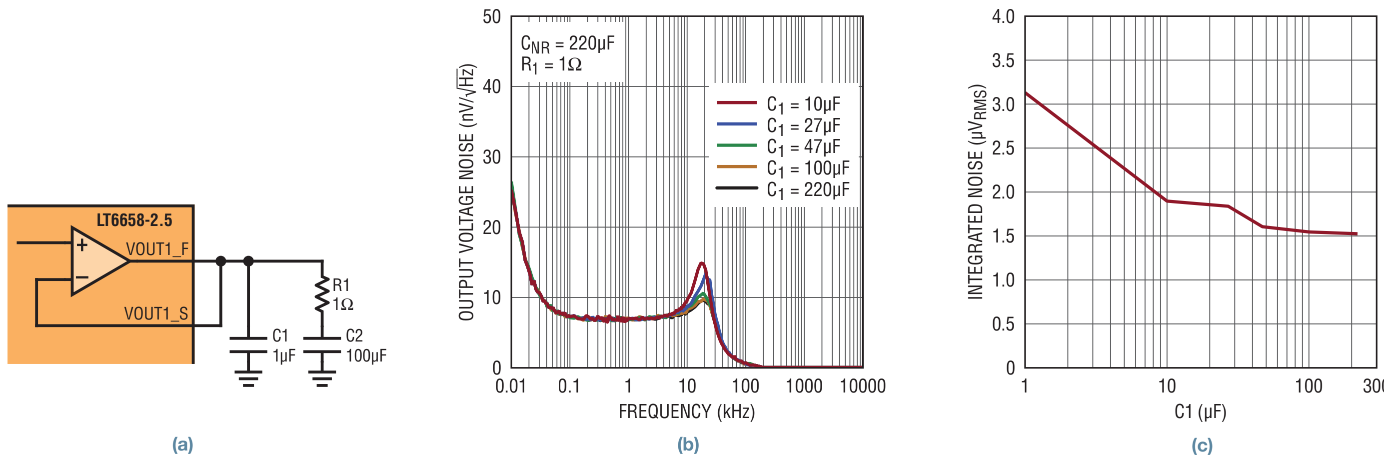
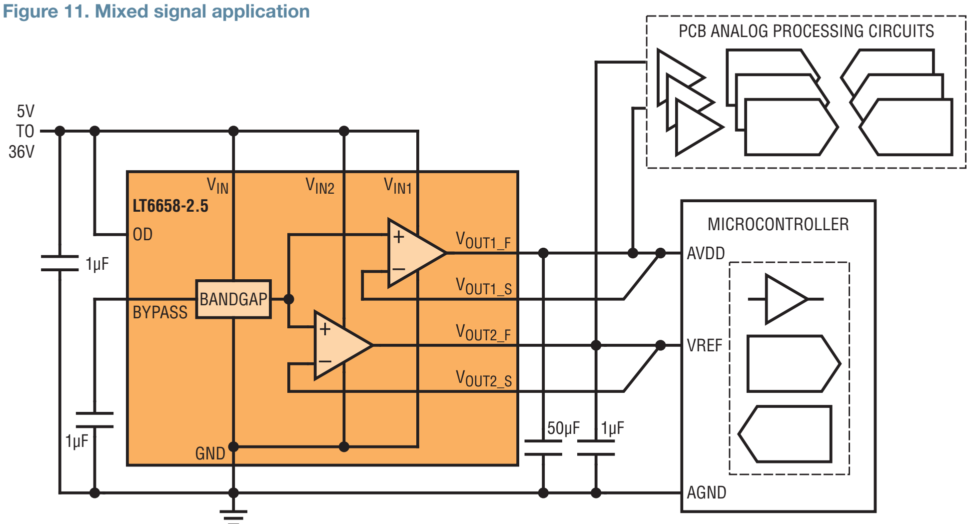


Figure 10. Reduce noise peaking by adding a 1Ω resistor in series with C2.

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 1µF ceramic capacitor in parallel with the larger capacitor.

One drawback of this scheme is the noise peaking, which can add to the total integrated noise. To reduce the noise peaking, a 1Ω 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 11. Mixed signal application



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.

The LT6658 is 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.

Figure 12. Data acquisition solution

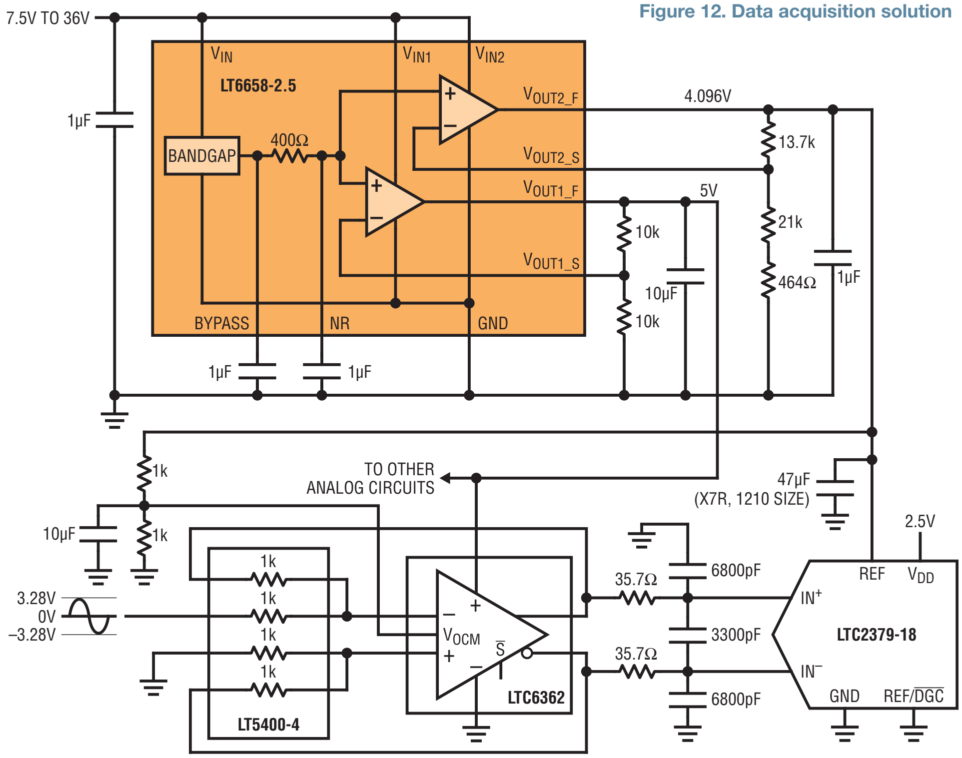


Table 2. Data acquisition circuit example from Figure 12.

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

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 2.5V output to a 4.096V reference voltage and to provide a common mode voltage to the input amplifier, LTC6362. V_{OUT1} is gained up to 5V, providing power to the LTC6362 and other analog circuits that require a 5V rail. Both LT6658 outputs have the maximum load at 150mA and 50mA on V_{OUT1} and V_{OUT2}, respectively.

The SNR, ENOB and THD of this circuit verify the superior performance of the LT6658 as shown in Table 2.

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 3.3V rail to a noisy FPGA supply (VCCIO) and some miscellaneous logic on one channel, and 5V to the reference input of the 20-bit ADC on the other channel.

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.

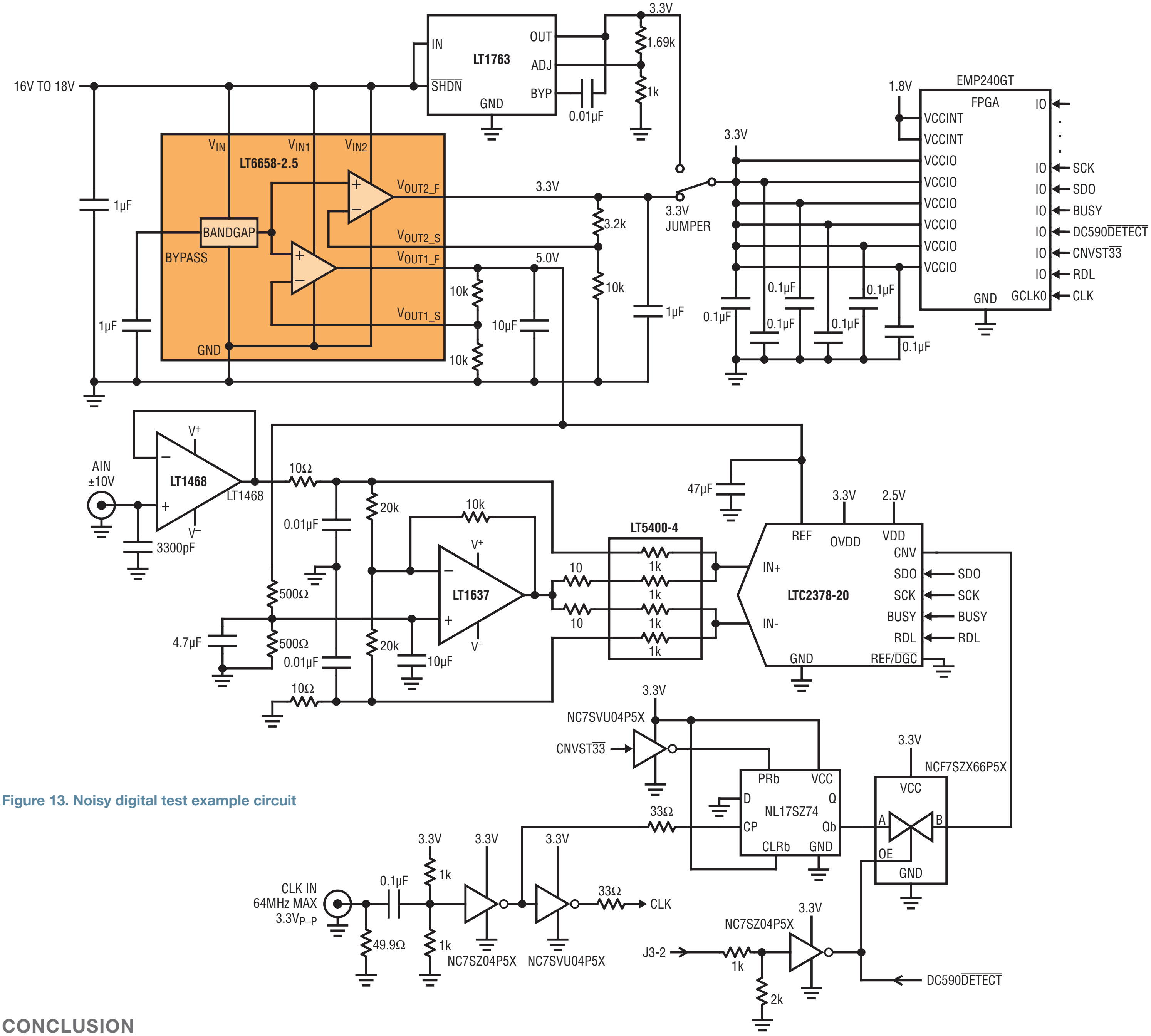


Figure 13. Noisy digital test example circuit

CONCLUSION

The LT6658 is the next step in the evolution of references and regulators. The precision performance and ability to provide a combined 200mA 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. ■

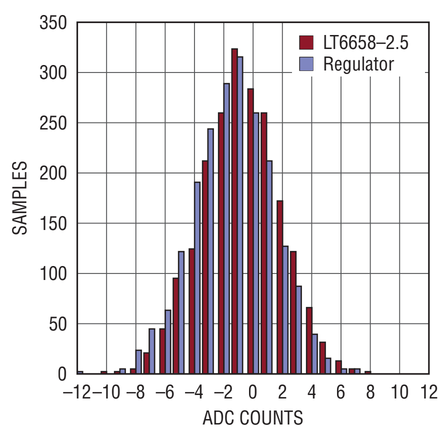


Figure 14. Histogram test results of the circuit in Figure 13