

Powering High Speed Analog-to-Digital Converters with Switching Power Supplies

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Introduction

Modern electronic systems utilizing analog-to-digital converters (ADCs) demand lower power and higher performance. This article describes the differences between linear and switching supplies and demonstrates that combining a high performance ADC with an efficient dc-to-dc converter can significantly reduce system power without degrading its performance.

System designers are being asked to reduce overall power in order to lessen the impact on our environment, while reducing both capital and operating costs. They are also being asked to increase circuit density so that electronic systems can be pushed into smaller form factors and operate in harsher environments. Unfortunately, incorporating high power solutions into these systems causes significant difficulties in removing the excess heat and leaves the other objectives unfulfilled.

Traditionally, ADC manufacturers have recommended using linear voltage regulators to provide clean power supplies for the converter. The linear regulators reject low frequency noise often present in system power supplies. In addition, a combination of ferrite beads and decoupling capacitors is used to attenuate the high frequency noise. This technique is effective, but it limits efficiency, especially in systems where linear regulators must regulate down from a power rail several volts above their output voltage. LDOs typically offer 30% to 50% efficiency, whereas the efficiency of a dc-to-dc regulator can be greater than 90%. Figure 1 shows the typical efficiency of a step-down switching regulator, Analog Devices ADP2114.

DC-to-DC converters, while much more efficient than LDOs, have traditionally been considered too noisy to directly power high speed analog-to-digital converters without significant performance degradation. This noise has at least two sources: noise coupled directly into the converter through supply ripple and noise due to magnetic coupling effects. The ripple can appear as distinct tones (or spurs) in the ADC's output spectrum or cause an overall elevation in the noise floor. The ADC's susceptibility to these distinct tones can be characterized and is often specified in converter data sheets as power supply rejection ratio (PSRR). PSRR measurements, however, do not characterize wideband effects on a converter's noise floor. The high currents produced in a switching power supply often lead to strong magnetic fields that can couple into other magnetic components on the board, including inductors found in matching networks and transformers used to couple analog and clock signals. Careful board layout techniques must be utilized to prevent these fields from coupling into critical signals.

Power Savings (Efficiency Advantages)

While semiconductor companies continue to introduce higher efficiency ADCs, DACs, and amplifiers, these improvements are small compared with the overall system power efficiency that can be obtained by replacing LDOs with dc-to-dc regulators. Consider a linear circuit that requires 100 mA, or 330 mW from a 3.3 V supply. With a typical LDO regulating 5 V down to 3.3 V, the overall power consumption would be 500 mW, while only 330 mW would provide a useful function. The raw supply must be 51% larger than actually necessary, resulting in both wasted energy and higher cost. By comparison, consider a dc-to-dc regulator with 90% efficiency. The total demand from a 5 V source would be 74 mA, a significantly smaller requirement, reducing both power and cost over time.

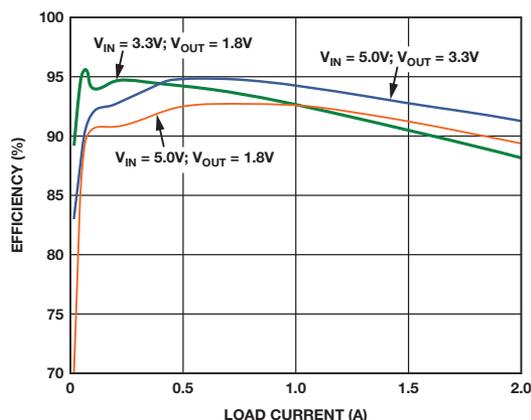


Figure 1. Typical efficiency of ADP2114 switching regulator.

In systems such as wireless base stations, power is often derived from a single high current power supply. Often this power gets regulated down through a number of different step-down stages before reaching the linear and mixed-signal components. Each of these step-down stages, although they may be quite efficient, results in some wasted power. The figure below shows a typical system where power is regulated down from a 12 V power rail. Three or more step-down stages may be involved in providing power to the ADC and other analog components. The last stage, which is typically an LDO, is often the least efficient of the step-down stages. Even efficient dc-to-dc regulators that achieve 90% efficiency result in only about 81% efficiency when cascaded twice, as shown in Figure 2. This gets even worse when LDOs must follow for the final regulation stage.



Figure 2. Typical system level power supply.

Recent improvements in dc-to-dc power supply technology and higher switching frequencies have enabled ADC operation directly from dc-to-dc power supplies with no loss in performance and significantly greater efficiency. Figure 3 shows a typical step-down circuit with the LDO eliminated.



Figure 3. Reduced system level power supply.

In addition, many systems employ a separate LDO for each ADC. Separate LDOs have been used to provide noise isolation between different ADCs and to reduce the power dissipated in each LDO. This separation spreads out the heat generated by the LDOs and allows the use of LDOs in small packages. Due to the higher efficiency of switching converters, one switcher can power several ADCs and other linear components, without excessive power dissipation and heat generation that would occur using a single large LDO. Using filtering ferrite beads at the output of the switching supply provides isolation between components that share the same power rail. The use of a switcher decreases the need for regulators in the system, resulting in significant power savings and reduced board cost by eliminating redundant LDOs and associated circuitry.

From the Lab

A 16-bit, 125 MSPS analog-to-digital converter such as Analog Devices AD9268 achieves very low noise with a 78 dB signal-to-noise ratio (SNR) specification. The low noise floor of -152 dBm/Hz makes it an ideal candidate for evaluation with a switching power supply. Any additional noise or spurious content contributed by the dc-to-dc converter would be easily visible in the converter's output spectrum. The converter was paired with an Analog Devices

ADP2114 PWM step-down regulator. This dual output step-down regulator is up to 95% efficient, operates at a high switching frequency, and has low noise.

A lab study compared the ADC's performance with linear regulators vs. its performance when using a switching regulator. These experiments were performed using the converter's customer evaluation board. The converter has two input supplies: AVDD powers the analog portion, while DRVDD powers the digital and output sections. For comparison, the converter was initially evaluated with two linear regulators (Analog Devices ADP1706), supplying both AVDD and DRVDD voltages. The setup for this test is shown in Figure 4. The converter was then powered with a switching regulator, as shown in Figure 5. One of the switching regulator's outputs supplied AVDD; the second output supplied DRVDD.

In both setups, the analog input source was a Rhode & Schwartz SMA-100 with a K&L band-pass filter. The analog input was supplied through a double balun input network, which converts the single-ended output from the signal generator to a differential input for the ADC. The sample clock source was a low jitter Wenzel oscillator, which was also supplied through a balun circuit for single-ended-to-differential conversion. The input supply rail (ahead of the regulators) was set to 3.6 V for both measurements.

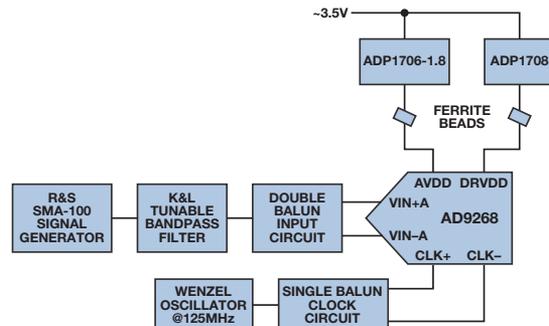


Figure 4. Block diagram for linear power supply measurements using ADP1708 LDOs.

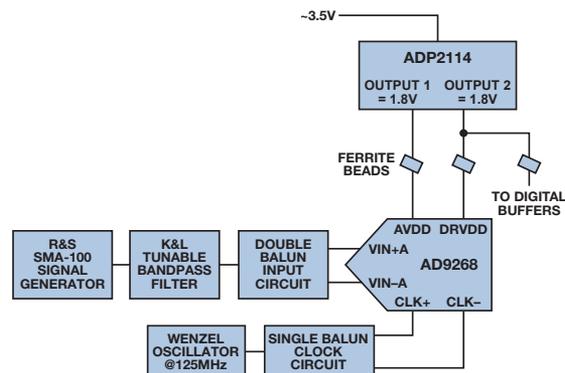


Figure 5. Block diagram for switching power supply measurements using ADP2114 switching regulator.

ADC Performance Results

The converter performance was measured with each supply configuration to determine if any degradation occurred when using the switching supplies. The SNR and SFDR were measured over a number of input frequencies; the results, summarized in Table 1, show no significant difference in SNR or SFDR when using linear regulators vs. using the switching supplies.

The switching regulator can run asynchronously or it can be synchronized to the converter's sample clock without affecting the converter's performance. Synchronization allows for additional freedom in applications where it may be advantageous.

Table 1. Performance Comparison: Linear Supplies vs. Switching Regulator

Analog Input Frequency (MHz)	Linear Supplies		Switching Supply	
	SNRFS	SFDR	SNRFS	SFDR
10.3	79.2	92.2	79.2	92.3
70.0	78.5	91.0	78.4	90.8
100.3	77.8	85.8	77.7	85.6
140.3	76.9	85.0	76.9	84.8
170.3	76.2	84.3	75.9	84.6
200.3	75.0	76.9	75.0	77.0

FFT Plots

Figure 6 and Figure 7 show FFTs of the AD9268 with a 70 MHz analog input frequency using linear supplies vs. switching supplies.

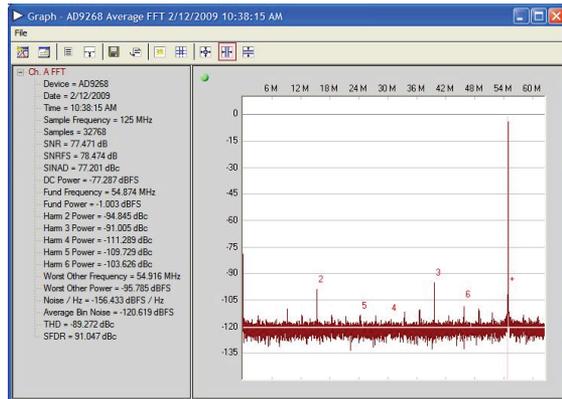


Figure 6. 70 MHz A_{IN} with ADP1708 linear supplies.

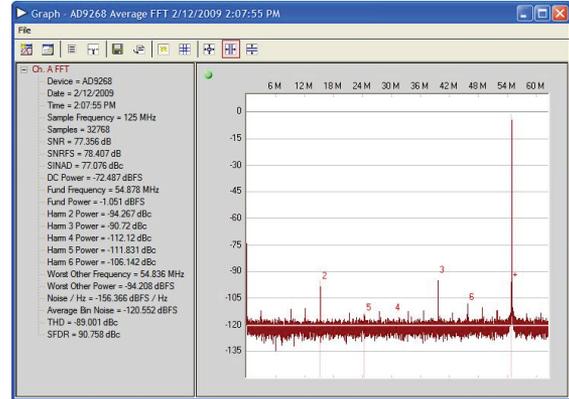


Figure 7. 70 MHz A_{IN} with ADP2114 switching supplies.

Efficiency Results

Table 2 shows the measured efficiency of each power solution. With a 3.6 V input voltage, the switching regulator provides a 35% improvement in efficiency and a savings of 640 mW. This savings is for a single converter and would be amplified dramatically in systems utilizing multiple ADCs.

Table 2. Efficiency Comparison: Linear Supplies vs. Switching Regulator

	Linear Regulators	ADP2114 Switching Regulator
Input Voltage/Current	3.6 V/0.433 mA (1.5588 W)	3.6 V/0.255 mA (0.918 W)
Output Voltage/Current	1.8 V/0.433 mA (0.7794 W)	1.8 V/0.433 mA (0.7794 W)
Overall Efficiency	50%	85%

Thermal Images

Figure 8 and Figure 9 below show the differences in heat generated in the power supply section of the board between using the LDO supply vs. the ADP2114. The same scaling is applied to both images. Measurement points SP01, SP02, and SP03 show the temperature of the linear regulators, which are operational in Figure 8. SP06 in Figure 9 shows the temperature of the ADP2114, which is 10°C to 15°C lower than the linear regulators shown in Figure 8. SP04 shows the temperature of the AD9268, which is similar in both images. Also note that in Figure 8 the overall background temperature is higher, and a series blocking diode (unlabeled) is handling a much higher thermal load.

Circuit Details

Figure 10 shows the detailed circuit diagram used for the switching regulator, which was configured to operate in the forced PWM mode with the channels set up for 2 A individual outputs. The regulator's switching frequency was

set to 1.2 MHz by placing a 27 kΩ resistor between the FREQ pin and GND. In addition to the circuit shown, an additional ferrite bead was included between the switcher and the ADC, and standard bypass capacitors were placed near the ADC supply pins. This design achieves 220 μV of switching ripple and less than 6 μV of high frequency noise at the output of the ADP2114. The additional ferrite bead and bypassing near the AD9268 reduce this to 300 nV and less than 3 μV noise at the ADC power pins.

The bill of materials and layout information are provided as well. Note in the layout that the switching inductors L101 and L102 are on the opposite side of the board from the ADC and signal path components. This placement helps to minimize any potential coupling between these inductors and the components on the top of the board, particularly the baluns in the signal and clock paths. In any layout with a switching converter, care should be taken to avoid magnetic or electric field coupling.



Figure 8. Thermal image of AD9268 evaluation board with linear power supply.



Figure 9. Thermal image of AD9268 evaluation board with ADP2114 supply.

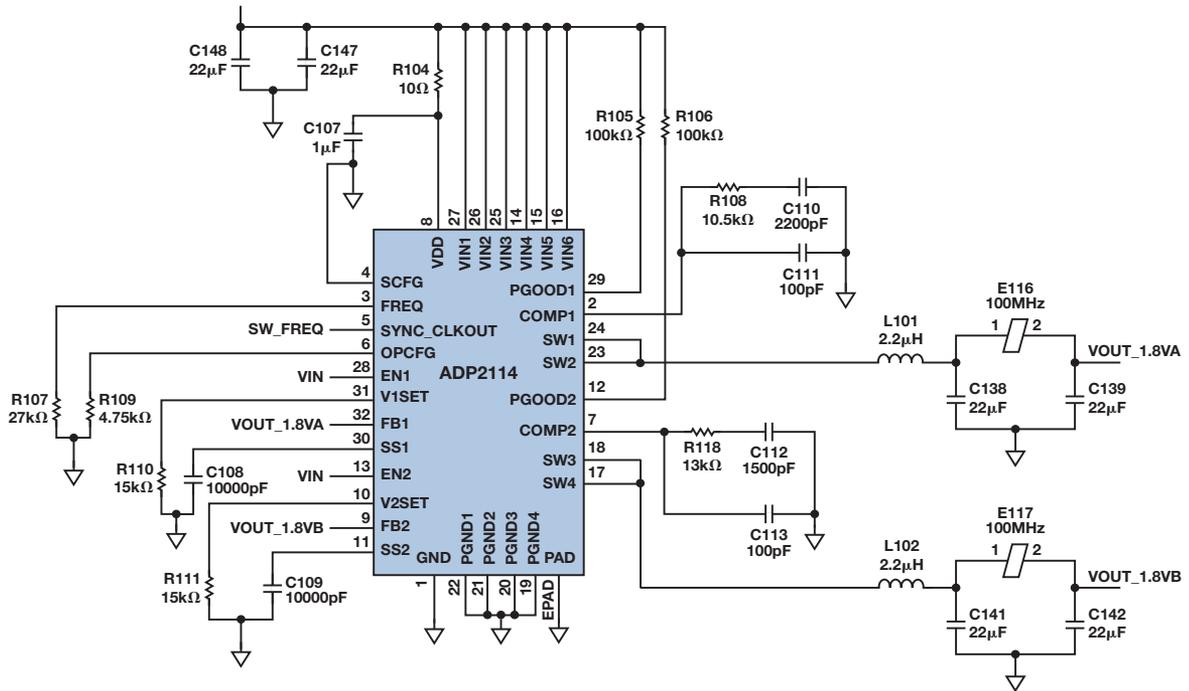


Figure 10. ADP2114 circuit configuration.

Table 3. Bill of Materials

Quantity	Reference Designator	Description	Manufacturer	Part Number	Package Type
1	C107	1 μ F CAP CER	Panasonic	ECJ-0EF0J105Z	C0402
2	C108, C109	10000 pF CAP CER MULTILAYER X7R 0402	Panasonic	ECJ-0EB1E103K	C0402
1	C110	2200 pF CAP CER	Phycomp (Yageo)	0402R222K8B20D	C0402
2	C111, C113	100 pF CAP CHIP MONO CER COG 0402	Murata	GRM1555C1H101JD01D	C0402
1	C112	1500 pF CAP CER 0402	Panasonic	ECJ-0EB1H152K	C0402
6	C138, C139, C141, C142, C147, C148	22 μ F CAP CER CHIP	Murata	GRM21BR60J226ME39L	C0805
2	E116, E117	100 MHz INDUCTOR FERRITE BD	Panasonic	EXC-ML20A390U	L0805
2	L101, L102	2.2 μ H INDUCTOR SM	Toko	FDV0630-2R2M	LSML291W264H118
1	R104	10 Ω RES PREC THICK FILM CHIP R0402	Panasonic	ERJ-2RKF10R0X	R0402
2	R105, R106	100 k Ω RES PREC THICK FILM CHIP R0402	Panasonic	ERJ-2RKF1003X	R0402
1	R107	27 k Ω RES CHIP SMD 0402	Panasonic	ERJ-2RKF2702X	R0402
1	R108	10.5 k Ω RES PREC THICK FILM CHIP R0402	Panasonic	ERJ-2RKF1052X	R0402
1	R109	4.75 k Ω RES CHIP SMD 0402	Panasonic	ERJ-2RKF4751X	R0402
2	R110, R111	15 k Ω RES CHIP SMD 0402	Panasonic	ERJ-2RKF1502X	R0402
1	R118	13 k Ω RES FILM SMD 0402	Yageo	9C04021A1302FLHF3	R0402
1	VR101	IC ADI DUAL CONFIG SYNC PWM STEPDOWN REG	ADI	ADP2114	QFN32_5X5_PAD3_3X3_3

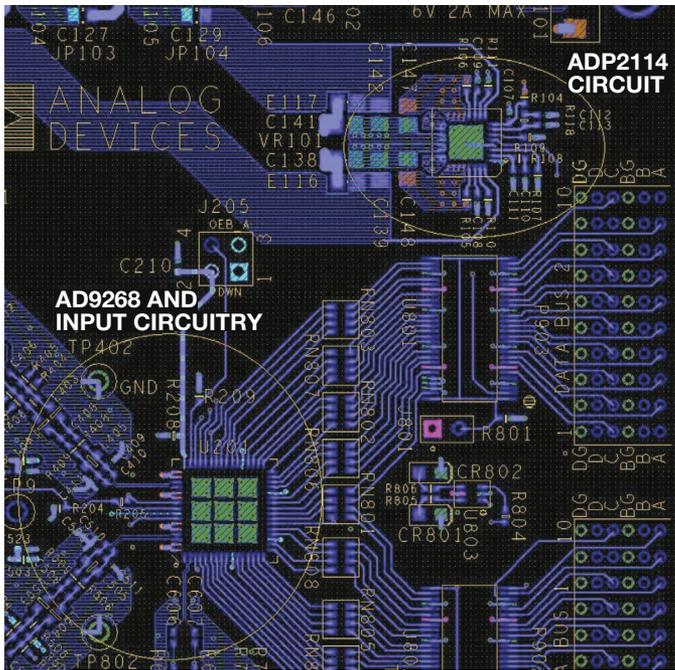


Figure 11. PCB layout showing relative location of ADP2114 and the AD9268 (note the switching inductors are on the opposite side of the PCB).

Conclusion

This article demonstrates that analog-to-digital converters can be powered directly from switching power supplies with no loss in performance if careful design practice is followed. The converter's performance showed no degradation when powered from the ADP2114 switching supply vs. ADP1708 linear supplies. Using a switching power supply can improve supply efficiency by 30% to 40% and significantly reduce overall power consumption—even more than simply selecting a lower power converter. In many systems, these devices are running continuously, so employing switching power supplies results in significantly lower operating costs with no penalty in performance.

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