Data Converters for Noisy Environments

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Noise generators are pervasive in today's industrial application world. Knowing the characteristics and understanding the behavior of noise sources is valuable to designers and users of electronic circuits. This TechNote defines some fundamental concepts of noise and later focuses on the selection and design of filters to use in conjunction with ADCs.

Noise is generally caused by electromagnetic interference (EMI), radio frequency interference (RFI), and ground loops. Common-mode noise in terms of ac power is the noise signal between the neutral and the ground conductor. This should not be confused with normal mode noise, which is referenced from the line (hot) and the neutral conductor.

Common-mode noise impulses tend to be higher in frequency than the associated normal-mode noise signal. This is to be expected since the majority of the common-mode signals originate from capacitive-coupled normal-mode signals. The higher the frequency, the greater the coupling among the conductors, line, neutral and ground. Electronic equipment is 10 to 100 times more sensitive to common-mode noise than normal-mode noise.

The amount of noise present on the power line can be surprising at any given time. The source of this noise is from the electrical distribution system external to the building as well as the distribution system within the building. It is the result of the power line's dynamic nature due to the ever-changing loads. Fig. 1 shows typical noise sources found on a power line.

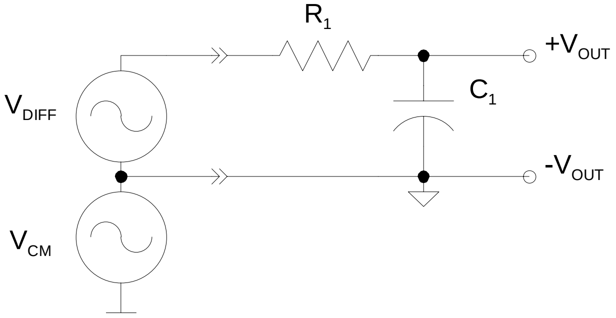

Fig. 1: Typical Noise Sources On A Power Line

Conventional power transformers and isolation transformers will not block normal-mode noise impulses, but if the secondarys of these transformers have the neutral bonded to ground, then they serve to convert normal-mode noise into common-mode noise. From the standpoint of microelectronic circuits, common-mode noise is more potentially harmful than normal-mode noise.

In a data acquisition system the effects of noise can be reduced by taking advantage of an ADC with differential inputs. Balancing the impedances allows you to convert noise sources into common-mode signals that an ADC with differential inputs can reject.

Differential signals are more suitable for use in most industrial applications. Measuring differential signals, the common-mode noise is dramatically reduced, if not completely eliminated. For such environments Burr-Brown products from Texas Instruments offer advantages using differential signals.

An ADC specifically designed for noisy environments is the ADS8364 (see Fig. 2).

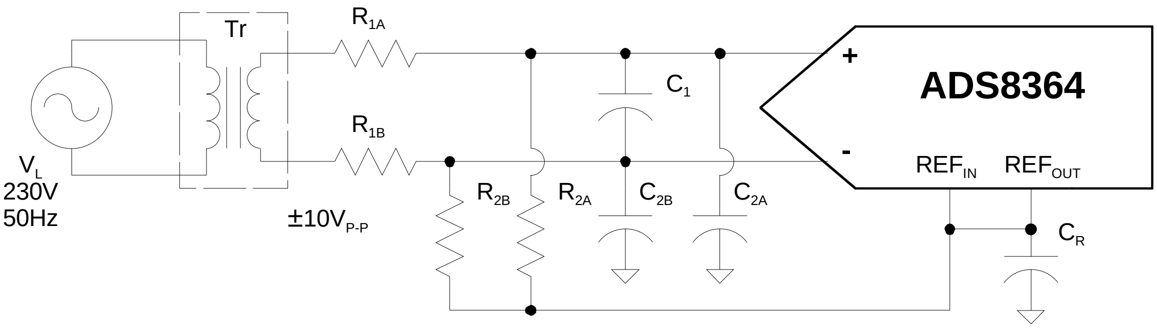

Fig. 2: Typical Application Circuit For The ADS8364

The input signal is ±2.5 V around 2.5 V. In industrial power metering for example, the output of the voltage measurement transformer typically is ±10 V. Before applying the meter outputs to the ADC, the signal needs to be scaled and offset to fit the differential input range of the converter.

The resistors R_{2A} and R_{2B} offset the output signal from the transformer around the reference voltage, $V_{REF,}$ of the ADC. The resistor networks, $R_{1A}/R_{2A,}$ and $R_{1B}/R_{2B,}$ scale the differential input signal to the full scale range (FSR) of the ADC. The scaling factor of these networks is given in Eq. 1. For correct operation the networks must be indentical. Differential and common-mode attenuations are equal:

$$G_{DIFF} = G_{CM} = \frac{R_{2A}}{R_{1A} + R_{2A}} = \frac{R_{2B}}{R_{1B} + R_{2B}} \qquad \text{Eq. 1}$$

Resistors R_{1A} and R_{1B} need to be large enough to avoid loading the signal source. They also provide additional input-overload protection isolating the ADC's input from the external signal source.

The next stage is to implement a low-pass filter to filter the noise from the differential signal. Adding capacitor C1 between + and – inputs will create a differential filter.

Also the common-mode signal that occurs will be attenuated by the resistor divider and then filtered. The cut-off frequency of the common-mode signal is given in Eq. 2.

$$BW_{CM} = \frac{1}{2 \cdot \pi \cdot \frac{R_{1A} \cdot R_{2A}}{R_{1A} + R_{2A}} \cdot C_{2A}} = \frac{1}{2 \cdot \pi \cdot \frac{R_{1B} \cdot R_{2B}}{R_{1B} + R_{2B}} \cdot C_{2B}} \qquad \text{Eq. 2}$$

And the -3dB differential bandwidth of this filter is given by Eq. 3.

$$BW_{DFF} = \frac{1}{2 \cdot \pi \cdot \frac{2 \cdot R_{1A} \cdot R_{2A}}{R_{1A} + R_2 A} \cdot (C_1 + \frac{C_{2A}}{2})} \qquad \text{Eq. 3}$$

Any mismatch between the time constants of the two common-mode filters will unbalance the input bridge and reduce high-frequency common-mode rejection. The C1 capacitor connected across the bridge output reduces effectively any ac common-mode rejection errors from component mismatch.

For example, making C_1 ten times larger than C_{2A} or C_{2B} provides 20 times reduction in common-mode rejection error arising from C_{2A}/C_{2B} mismatch.

Measurement Results

Measurements were made with the ADS8364 operating with a clock of 3.8 MHz and sampling at 38 kHz. This determines a conversion time of 4.47 µs and an acquisition time of 21.84 µs. The choice of the resistors values for R1A/R1B was 4 kΩ and for R2A/R2B was 4 kΩ. The value of C1 was varied from 0 to 3.3 nF. Tabe 1 shows the measurements made and Figs. 3 and 4 tabulate some of the data.

Capacitor (nF)			Ac Performance (dB/dBc)				Harmonics (dB)			
C1	C2a	C2b	SNR	SINAD	SFDR	THD	3rd	5th	7th	9th
0.00	0.00	0.00	84.85	83.71	90.64	-90.05	-90.64	-102.28	-102.42	-114.13
0.56	0.00	0.00	85.31	84.79	98.25	-94.28	-98.25	-98.51	-101.00	-122.03
1.00	0.00	0.00	85.33	84.87	98.10	-94.77	-98.10	-99.85	-101.57	-122.85
1.20	0.00	0.00	85.51	85.02	98.38	-94.67	-98.73	-99.18	-101.07	-115.52
1.50	0.00	0.00	85.26	84.86	98.23	-95.36	-99.64	-99.70	-101.83	-124.32
1.80	0.00	0.00	85.30	84.97	98.07	-96.31	-101.43	-100.42	-102.41	-110.11
2.20	0.00	0.00	85.29	84.90	97.91	-95.57	-103.14	-100.06	-100.49	-105.11
3.30	0.00	0.00	84.20	81.85	88.41	-85.64	-88.41	-92.28	-93.82	-96.74
1.80	0.18	0.18	86.03	85.63	100.42	-96.16	-101.55	-100.42	-101.64	-113.80

After preliminary measurements the capacitors C2A/C2B were added. As can be seen, the lowest measured THD was for a value for C1 of about 2 nF. Choosing 1.8 nF for C1 and 0.18 nF for C2A/C2B gives an equivalent capacitance of 1.9 nF.

Adding common-mode capacitors improves SNR, SINAD and SFDR. The FFT results of the final circuit are presented in Fig. 5.

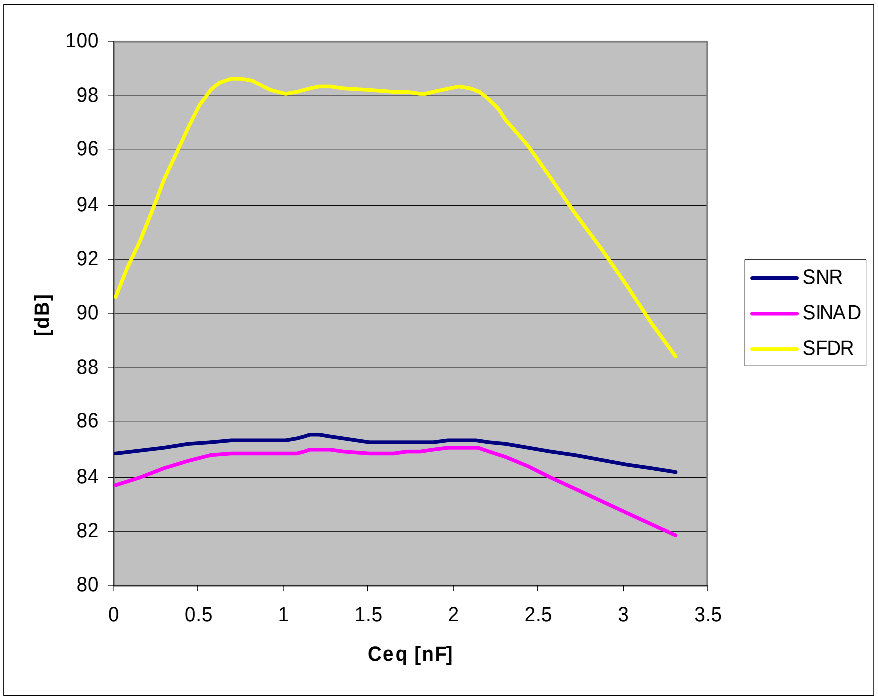

Fig. 3: Ac Performance Curves With Varying Equivalent Capacitance

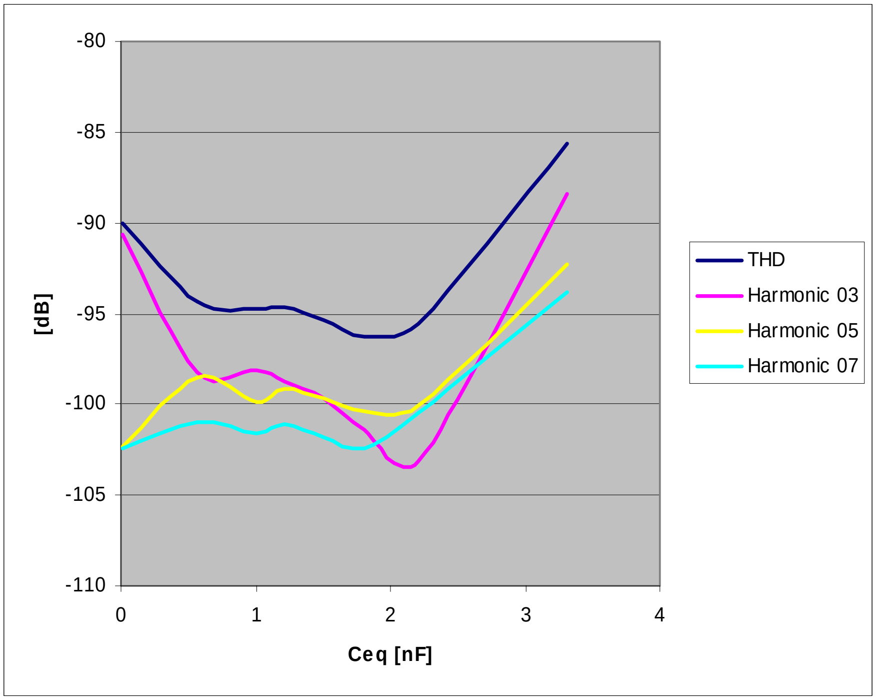

Fig. 4: Harmonics With Varying Equivalent Capacitance

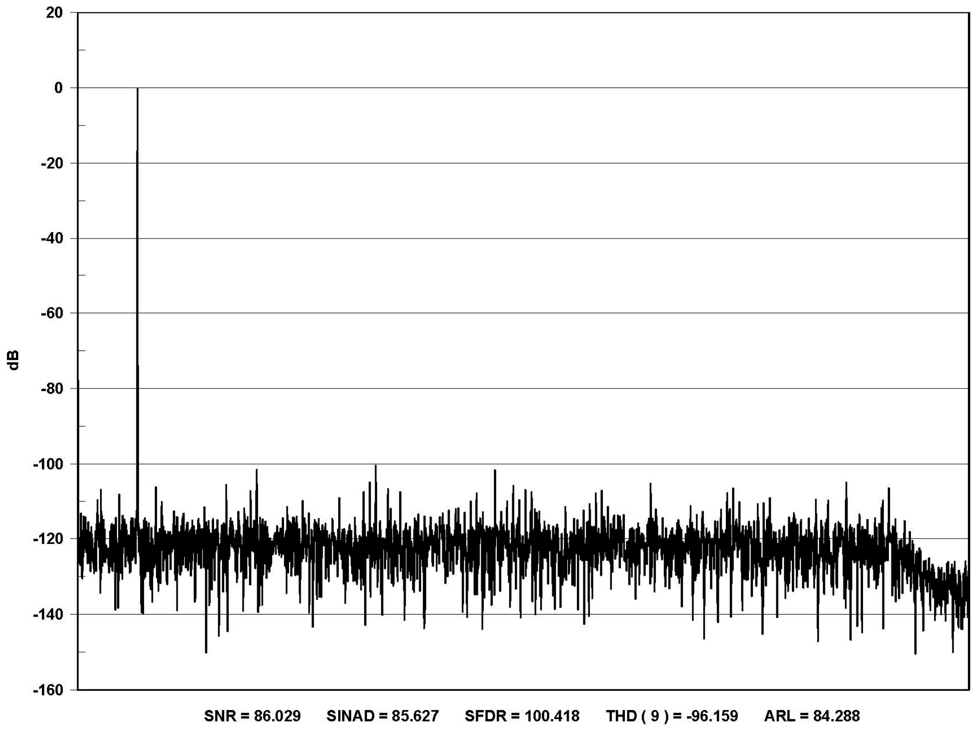

Fig. 5: 4096 Point FFT Spectrum (Fs = 50 kHz, Fin = 1.672363 kHz)

About The Authors

Miroslav Oljaca is in Motor Control Strategic Marketing for High Precision Analog at Texas Instruments. He has over 17 years of design and management experience in the fields of motor control and power conversion. Miroslav currently specifies and supports products for motor control solutions in high precision applications. He earned BSEE and MSEE degrees in electrical engineering at the Electrotechnical University in Belgrade (Yugoslavia). He is a member of the AEI, CNI, IEE and IEEE holding the titles of Eur Ing, Dott.Ing., MSc, and CEng. He can be reached at oljaca_miroslav@ti.com.

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