Keywords: ADC, Delta-Sigma, ENOB, SNR, SINAD, THD, signal-to-noise ratio, signal-to-noise and distortion ratio, total harmonic distortion, effective number of bits, analog-to-digital converter

APPLICATION NOTE 6854

HOW TO CALCULATE ENOB FOR ADC DYNAMIC PERFORMANCE MEASUREMENT

Abstract: SNR, SINAD, THD, and ENOB values are common measures of the dynamic performance of ADCs, and ENOB can be calculated directly from the known values of SNR and THD.

Introduction

The dynamic performance of an analog-to-digital converter (ADC) is determined by the effective number of bits (ENOB). In this application note, we examine the relationship of ENOB with other dynamic characteristics of ADCs such as signal-to-noise ratio (SNR), signal-to-noise and distortion ratio (SINAD), and total harmonic distortion (THD). We also compare the theoretically calculated ENOB of the MAX11216 24-bit high performance delta-sigma ADC to the measured value obtained in the lab.

How Are SNR, SINAD, THD, and ENOB Related?

Signal-to-Noise Ratio

Signal-to-noise ratio (SNR) is the fundamental frequency signal power level (P_S) to the noise power level (P_N) ratio and is mathematically expressed in Equation 1.

$$SNR = 10\log(P_S/P_N) = 10\log P_S – 10\log P_N. \quad \text{(EQ. 1)}$$

The ideal theoretical SNR is calculated directly from the resolution (N bit) as SNR = (6.02 × N + 1.76)dB. However, for delta-sigma ADCs like the MAX11216, which features internal programmable low-pass digital filters, the SNR can be increased by adjusting the amount of filtering. Filter more by reducing the filter bandwidth for a higher SNR, and filter less by increasing the filter bandwidth for a higher data rate.

Figure 1 shows a fast Fourier transform (FFT) of the MAX11216 with continuous mode, sinc filter, and buffer features. P_S is the fundamental frequency signal power level and P_N is the noise power level, resulting in an SNR of 110.4dB at a data rate of 8Ksps. FFT is an analog spectrum analyzer that measures the amplitude of the fundamental frequency and its various harmonics as well as the non-harmonic spurious and noise components of a digitized signal.

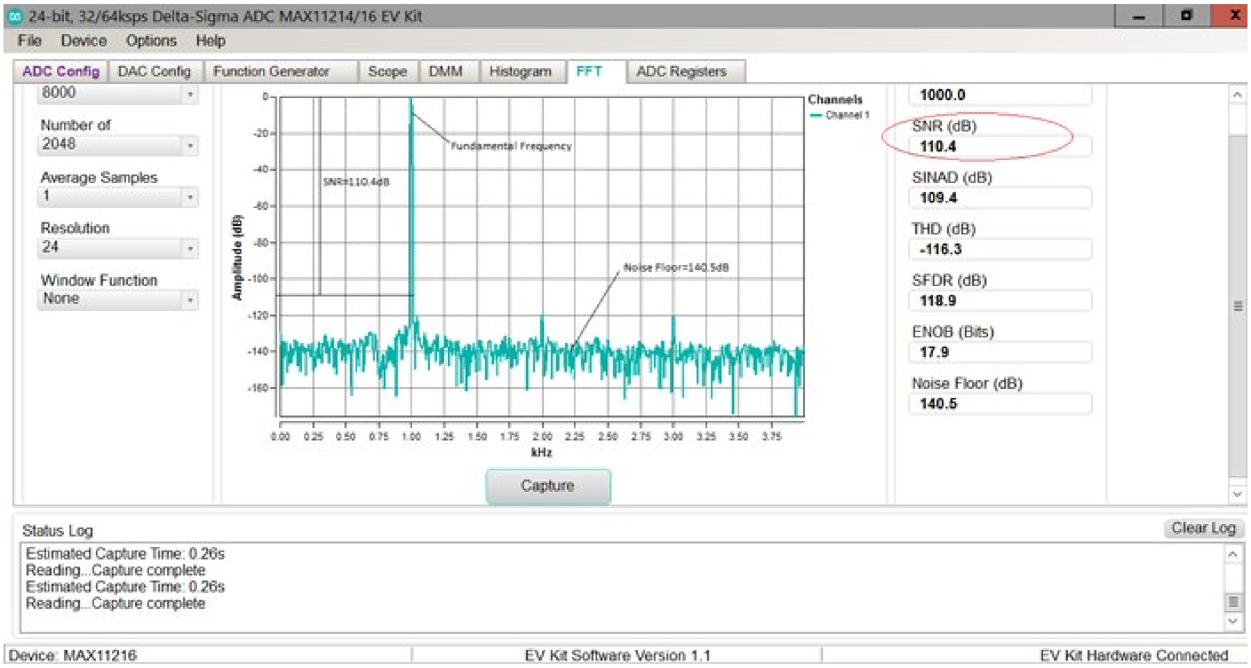

Figure 1. MAX11216 FFT with SNR = 110.4dB, sample rate = 8Ksps, f_{IN} = 1KHz, V_{AVDD} = 3.6V, V_{AVSS} = 0V, V_{REF} = 3.6V, T_A = +25°C, and external clock = 8.192MHz.

Signal-to-Noise and Distortion Ratio

Signal-to-noise and distortion ratio (SINAD) is the fundamental frequency signal power level (P_S) to the noise plus distortion power level (P_{N+D}) ratio. SINAD is mathematically expressed as in equation 2.

$$SINAD = 10\log[P_S/(P_{N+D}] = 10\log P_S - 10\log P_{N+D}. \qquad \text{(EQ. 2)}$$

Distortion includes the harmonics and spurious as shown in **Figure 2** of a MAX11216 FFT with continuous mode, sinc filter, and buffer features and SINAD = 109.4dB at a data rate of 8Ksps.

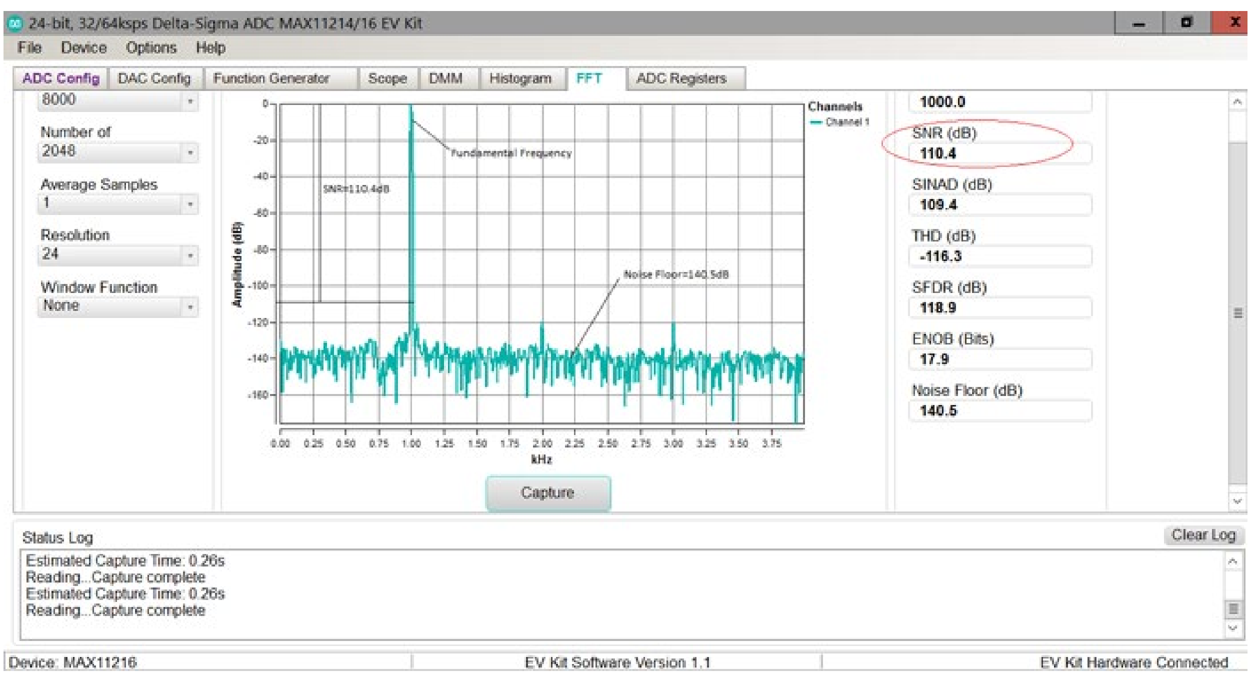

Figure 2. MAX11216 FFT with SINAD = 109.4dB, sample rate = 8Ksps, f = 1KHz, V = 3.6V, V =

IN AVDD AVSS

0V, V_{REF} = 3.6V, T_A = +25°C, and external clock = 8.192MHz.

Total Harmonic Distortion

Total harmonic distortion (THD) is the ratio of the fundamental signal power level to the power of the sum of its harmonics excluding noise. Generally, the first five harmonics contribute to the most distortion. Hence, in calculating THD, only the first five harmonics are used as shown in Equation 3.

$$THD\ (dB) = 10\log(P_S) – 10\log(P_2 + P_3 + P_4 + P_5 + P_6) \qquad \text{(EQ. 3)}$$

where P_S and P_2 to P_6 are in mW.
For example, if $P_S = P_1$ = 1mW, P_2 = 0.1nW, P_3 = 0.01nW, P_4 = 0.001nW, P_5 = 0.0001nW, and P_6 = 0.00001nW, then the THD is calculated as follows:
$THD(dB) = 10\log(1) – 10\log[(0.1 + 0.01 + 0.001 + 0.0001 + 0.00001) \times 10^{-6}]$
THD(dB) = -69.5074dB

If the sixth harmonic of 0.00002nW was counted, the THD would increase to -69.5070dB, which is very insignificant.

Figure 3 shows the MAX11216 with a THD of -116.3dB, an input frequency of 1KHz, a sample rate of 8Ksps, and continuous mode, sinc filter, and buffer features.

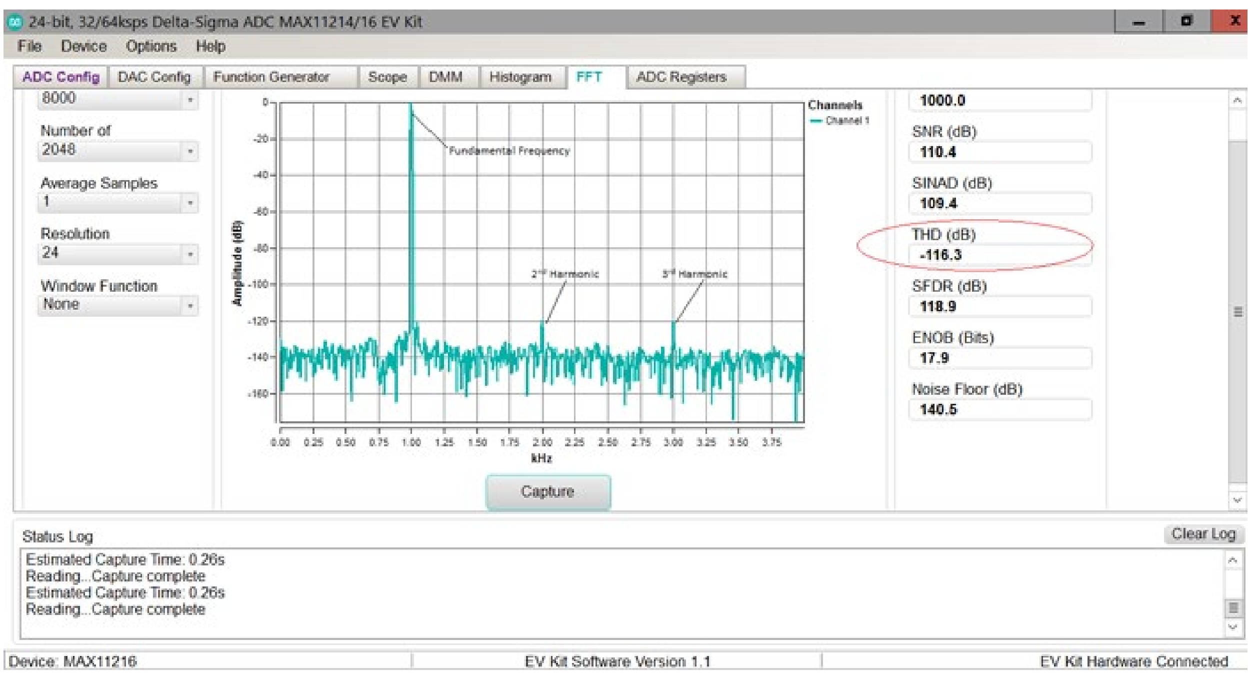

Figure 3. MAX11216 FFT with THD = 116.3dB, sample rate = 8Ksps, f_{IN} = 1KHz, V_{AVDD} = 3.6V, V_{AVSS} = 0V, V_{REF} = 3.6V, T_A = +25°C, and external clock = 8.192MHz.

Effective Number of Bits

The effective number of bits (ENOB) is the number of bits when both noise and distortion are considered and is mathematically expressed in Equation 4.

$$ENOB = (SINAD – 1.76)/6.02 \qquad \text{(EQ. 4)}$$

To express ENOB in terms of SNR and THD, see the following calculations:

1. Use Equation 2 and Equation 1 as follows to determine Equation 5:

$SINAD = 10\log[P_S/(P_{N+D}] = 10\log P_S – 10\log P_{N+D}$.
$SNR = 10\log (P_S/P_N)$
$\log (P_S/P_N) = ^{SNR/10}$
$P_S/P_N = 10^{SNR/10}$
$P_N/P_S = 10^{-SNR/10}$ (EQ. 5)

2. Equation 5 can be also expressed as follows:
   $P_D/P_S = 10^{-THD/10}$ (EQ. 6)
3. Add Equation 5 and Equation 6 to determine Equation 7.
   $(P_N+P_D)/P_S = 10^{-SNR/10} + 10^{-THD/10}$
   $P_S/(P_{N+D}) = 1/(10^{-SNR/10} + 10^{-THD/10}) = (10^{-SNR/10} + 10^{-THD/10})^{-1}$ (EQ. 7)
4. Substitute Equation 7 into Equation 2.
   $SINAD = 10\log(10^{-SNR/10} + 10^{-THD/10})^{-1}$
   $= -10\log(10^{-SNR/10} + 10^{-THD/10})$ (EQ. 8)
5. Finally, substitute Equation 8 into Equation 4 to obtain the ENOB equation in terms of SNR and THD as follows:
   $ENOB = \{[-10\log(10^{-SNR/10} + 10^{-THD/10})] – 1.76\}/6.02$ (EQ. 9)

MAX11216 ENOB

Table 1 lists the simulated MAX11216 SNR values for different data rates with a sinc digital filter where V_{IN} = 0V, V_{AVDD} = 3.6V, V_{AVSS} = 0V, V_{REF} = 3.6V, and T_A = +25°C.

Table 1. Simulated Continuous Mode SNR (dB) Versus Data Rate and PGA Gain with Sinc Filter

		Gain = 1	Gain = 8	Gain = 128
Data Rate (sps)	**Buffer**	**LN**	**LN**	**LN**
1.9	139.8	136.5	140.5	128
3.9	139.4	135.3	139.2	125.4
7.8	139.2	134.7	137.9	122.5
31.2	135.8	132.1	134.3	116.5
62.5	133.8	129.4	131.5	114
500	125.8	121.2	123.3	104.8
1000	123.1	118.5	120.4	101.8
4000	117.7	113.1	115.1	96.5
16000	114.6	109.9	112	93.4
64000	107.8	103.2	105.8	88.2

Table 2 lists the calculated ENOB values using Equation 9 based on the SNR values where THD = 120dB (typical specification in the MAX11216 data sheet), V_{IN} = 0V, V_{AVDD} = 3.6V, V_{AVSS} = 0V, V_{REF} = 3.6V, and T_A = +25°C.

Table 2. Calculated Continuous Mode ENOB (Bits) Versus Data Rate and PGA Gain with Sinc Filter

	ENOB			
Data Rate (sps)	Buffer	Gain = 1, Low Noise	Gain = 8, Low Noise	Gain = 128, Low Noise
1.9	19.6336811	19.62522357	19.63479484	19.53506307
3.9	19.6329602	19.62021353	19.63257437	19.45838575
7.8	19.63257437	19.61715616	19.62958982	19.3193091
31.2	19.62246601	19.59803115	19.61487866	18.79339941
62.5	19.6117322	19.56278581	19.59185023	18.4828525
500	19.4727366	19.23395095	19.3643726	17.09481505
1000	19.35361828	19.00585701	19.17360407	16.60710288
4000	18.92511435	18.36098144	18.62499223	15.73432624
16000	18.56137578	17.89619095	18.20615941	15.22101479
64000	17.57240744	16.83558105	17.25547296	14.35832751

Table 3 lists the measured ENOB values.

Table 3. Measured Continuous Mode ENOB (Bits) Versus Data Rate and PGA Gain with Sinc Filter

		Gain = 1	Gain = 8	Gain = 128
Data Rate (sps)	Buffer	LN	LN	LN
1.9	24.6	25.2	24.8	24.5
3.9	23.4	24.7	23.9	24.4
7.8	23.6	23.4	23.3	23.1
31.2	22.3	22.3	22.1	22
62.5	21.6	21.7	21.5	21.4
500	20.2	20.1	20.2	20
1000	19.7	19.6	19.5	19.3
4000	18.8	18.8	18.7	18.5
16000	18.3	18.8	18.5	18.6
64000	17.2	17.3	17.3	17.3

Figure 4, **Figure 5**, **Figure 6**, and **Figure 7** compare the measured and calculated ENOB values for the buffer, gain = 1, gain = 8, and gain = 128.

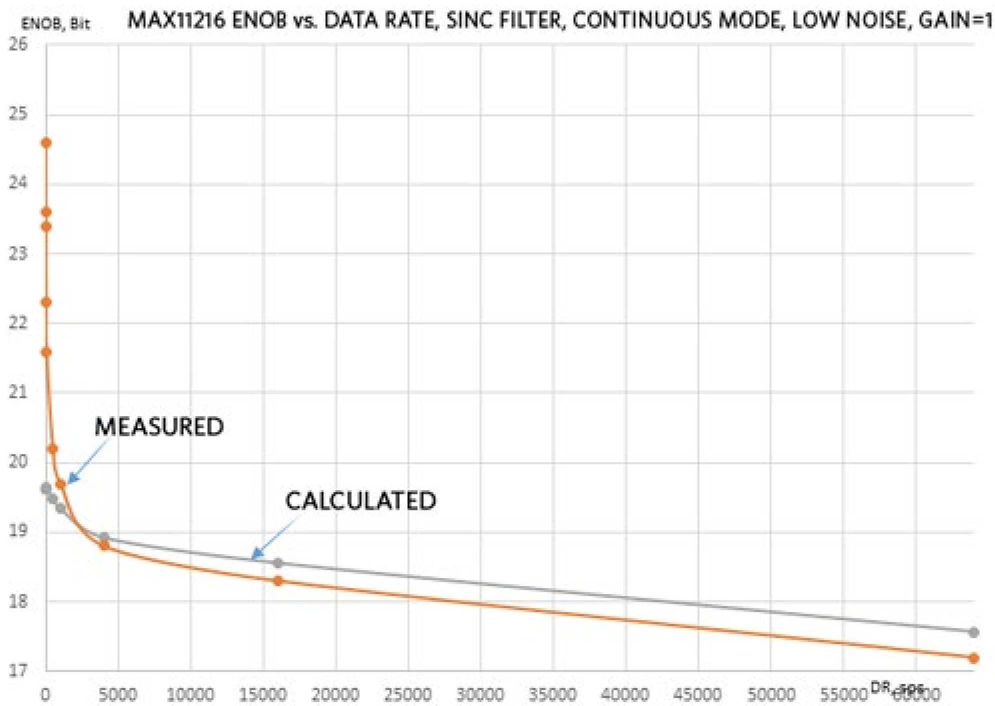

Figure 4. MAX11216 calculated and measured ENOB with sinc filter, continuous mode, and buffer.

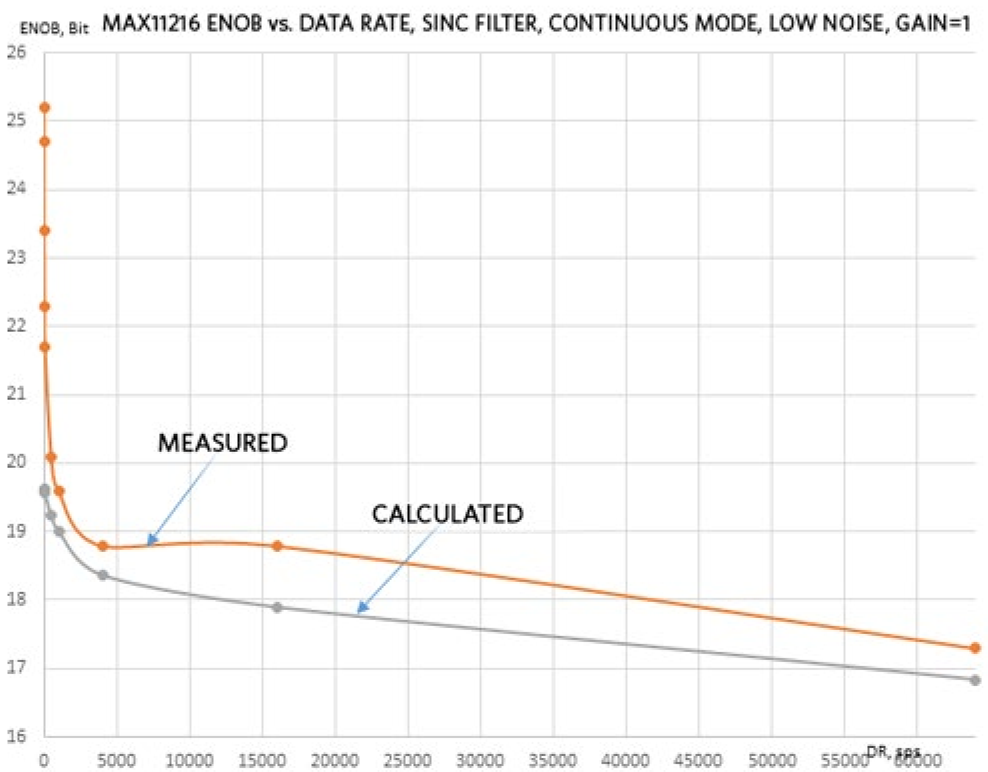

Figure 5. MAX11216 calculated and measured ENOB with sinc filter, continuous mode, and gain = 1.

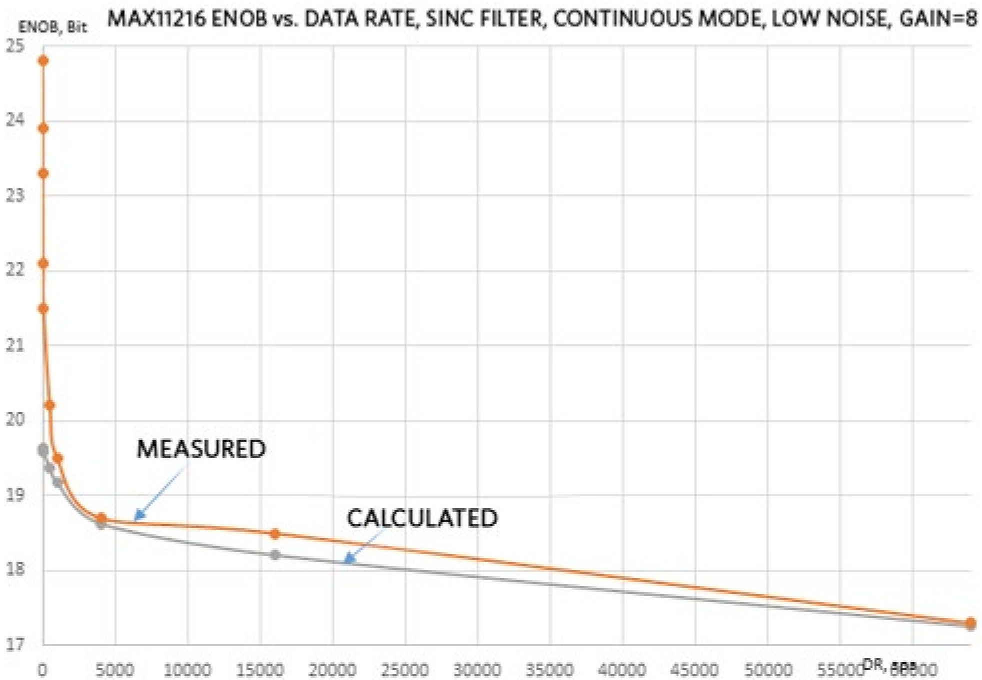

Figure 6. MAX11216 calculated and measured ENOB with sinc filter, continuous mode, and gain = 8.

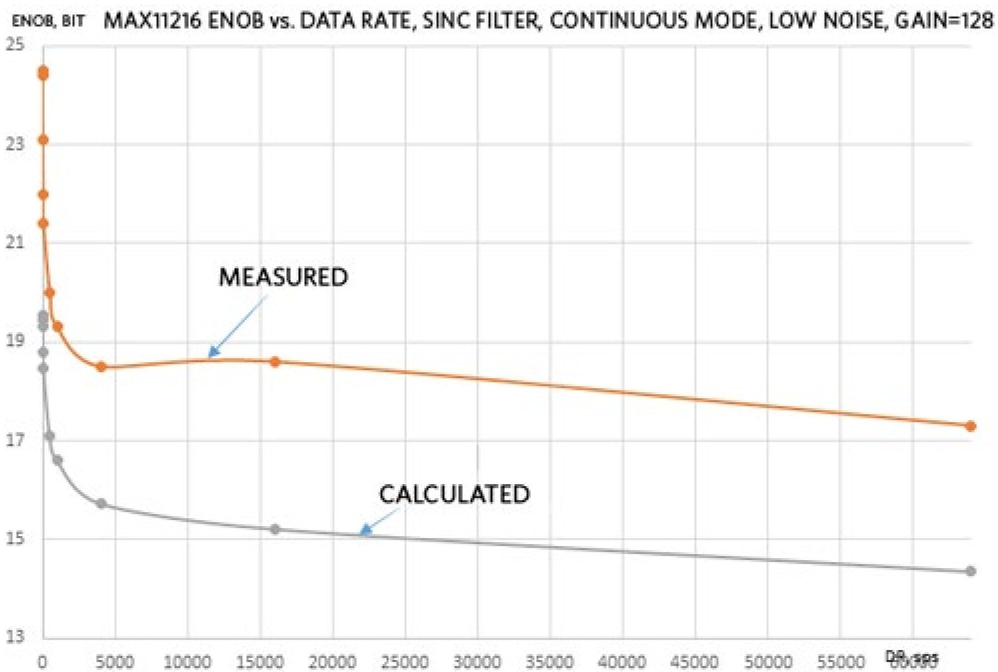

Figure 7. MAX11216 calculated and measured ENOB with sinc filter, continuous mode, and gain = 128

Figure 8 shows the measured ENOB values versus the data rates for the buffer and various PGA gains.

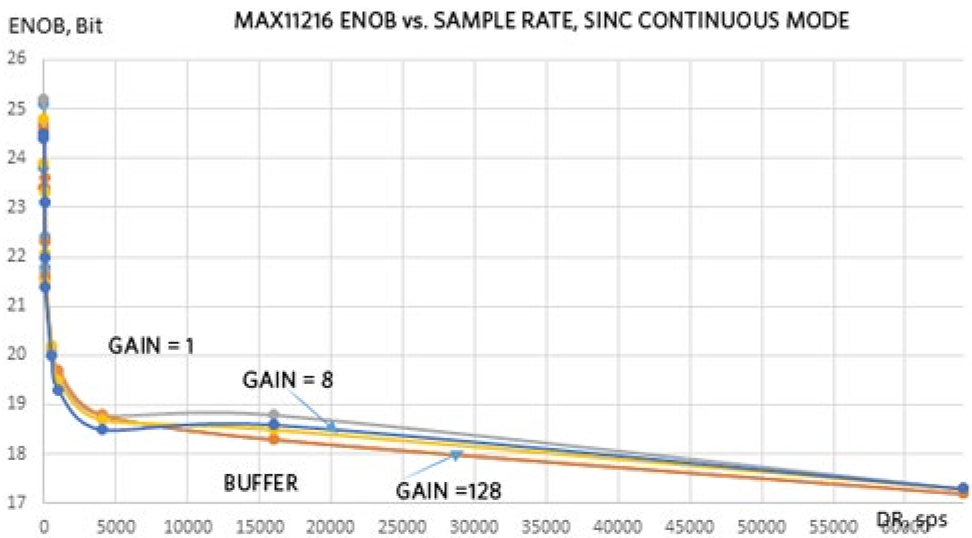

Figure 8. MAX11216 measured ENOB with the data rates for the buffer and various PGA gains.

Conclusion

The SNR, SINAD, THD, and ENOB values are common measures of the dynamic performance of ADCs. The ENOB can be easily and accurately calculated based on the signal-to-noise ratio (SNR) and the total harmonic distortion (THD). The MAX11216 ENOB values obtained in the lab confirm that the measured data matches closely with the values calculated based on the ENOB equation. For delta-sigma ADCs with internal programmable digital filters, the measured data also confirms that increasing the amount of filtering increases the SNR and ENOB.

Related Parts		
MAX11216	24-Bit, 10mW, 140dB SNR, 64ksps Delta-Sigma ADC with Integrated PGA	Samples

More Information
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