

Effects of Overdrive, Frequency, Sample and Error in Code Transition levels on Computation of ENOB of an A/D Converter

R. S. Gamad* and D. K. Mishra

*Department of Electronics & Instrumentation Engineering
Shri G. S. I T S, Indore, M.P., India – 452003
Corresponding auther. E-mail: rsgamad@gmail.com

Abstract

Effects of overdrive, frequency, and error in code transition levels on computation of effective resolution of an analog to digital converter (ADC) are presented in this paper. Error in code transition level is determined by deviation of actual code transition level from estimated value. Error in nonlinearity and effective Bits (EB) is computed by using error in code transition levels and computing corresponding values. 5 bit ADC transfer characteristics are simulated and arbitrary nonlinearity errors are introduced in it. Simulation results report a effects of overdrive, frequency and code transition error on ENOB with comparison of earlier published and present work.

Keywords: Effective number of bit, code transition level, additive noise standard deviation, overdrive and code transition error.

Introduction

A/D Converter is an important component which interfaces an analog system with a digital system. Due to inherent uncertainty in quantization process in ADC in addition to other errors, the determination of functional parameters are necessary in order to get proper accuracy and performance in a system. An ADC has gain error, offset error and nonlinearity error etc. in addition to ideal quantization error. Nonlinearity error present in a real life ADC can not be minimized so there is a need for determination of its actual values. Nonlinearity error depends upon ADC input frequency and sampling frequency. Effective resolution of an ADC is also a function of test frequency. It is necessary to determine the value of effective resolution at this test

frequency. With increase in input frequency nonlinearity error increases which results in decreases in value of effective resolution. Sine wave and triangular wave based histogram methods are popular in determining these errors of an ADC. First of all code transition levels of ADC transfer characteristics are computed by collecting large number of samples of full scale sine wave by test ADC. Recently work has been reported for computation of error in ADC transfer characteristics [1]-[7]. In this proposed work, we have used existing method of error computation in code transition level and based upon this error effective resolution of an ADC are computed. In addition to existing method of finding error in code transition level we have also computed error by estimating difference in actual code transition level and best fit code transition level.

Mathematical algorithm

A. Error in Code Transition Level

Threshold voltage $T(i)$ for level i is given by[7][8]

$$T(i) = -A \cos \left[\frac{\pi Ch[i]}{X} \right], i = 1 \dots 2^n \quad (1)$$

Where X is the number of samples and $Ch[i]$ is the cumulative histogram defined by

$$Ch[i] = \sum_{j=0}^{i-1} H[j], i = 1 \dots 2^n \quad (2)$$

$$H[0] = 0$$

The normalized code transition voltage U can be expressed as

$$U = \frac{T(i) - C}{A} \quad (3)$$

Where C = Offset and A = Peak amplitude of input

Error between estimated and actual transition voltage can be expressed as

$$e_{\hat{U}} = \mu_{\hat{U}} - U$$

Where $\mu_{\hat{U}}$ is the mean of the estimated transition voltage levels.

This error can also be expressed as [4]:

$$e_{\hat{U}} \approx -\cos \left[\int_{-\pi}^{\pi} \left(\frac{1}{2} + \frac{1}{2} \operatorname{erf} \left(\frac{U + \cos \psi}{\sqrt{2} \sigma_n} \right) \right) d\psi \right] - U \quad (4)$$

Further it can be simplified as

$$e_{\hat{v}} \approx -\cos \left[\pi + \frac{2\sqrt{\pi}}{\sqrt{2}\sigma_n} \left\{ \left(U - \frac{U^3}{6\sigma_n^2} + \frac{U^5}{40\sigma_n^4} \right) - \frac{\sqrt{\pi}}{\sqrt{2}\sigma_n} \left(\frac{U}{2\sigma_n^2} - \frac{U^3}{4\sigma_n^4} \right) \right\} \right] - U \quad (5)$$

B. Effects of parameters on ENOB

The ENOB may be considered as number of bits of a perfect ADC whose rms quantization noise error would be equal to total rms error from all sources in the ADC under test. The ENOB can be expressed as [5] [8]:

$$EB = N - \log_2 \left[\frac{\text{rms error (actual)}}{\text{rms error(ideal)}} \right] \quad (6)$$

$$\text{rms noise (i)} = \left[\frac{\int_{x(i)}^{x(i+1)} e^2 dx}{x(i+1) - x(i)} \right]^{\frac{1}{2}} \quad (7)$$

Where e is the error signal between output and input of transfer characteristic and is expressed as

$$e = p x + q \quad (8)$$

equation (23) passes through two points ($x(i)$, $e(i)$) and ($x(i+1)$, $e(i+1)$). The parameters p and q can be obtained as

$$P = \frac{e(i) - e(i+1)}{x(i) - x(i+1)} \quad (9)$$

$$q = \frac{1}{2}[e(i) + e(i+1) - p\{x(i) + x(i+1)\}] \quad (10)$$

The centre values of best fit transition level $V_{cbf}(i)$ is given by

$$V_{cbf}(i) = \frac{T_b(i+1) + T_b(i)}{2} \quad (11)$$

Simulation Results

Five bit ADC transfer characteristics is simulated and arbitrary nonlinearity error is introduced. Normalized transition voltages are computed by taking large number of samples of full scale sine wave with variation of overdrive by test ADC. The ADC input frequency is kept at 0.98MHz with sampling frequency of 5MHz. The mean of

estimated transition voltages is computed. Correct normalized transition voltage is taken as mean of estimated transition voltages. The corrected transition voltages of ADC transfer characteristics are calculated from mean of normalized transition voltage. The effect of overdrive in limiting the error due to presence of additive noise on transition voltages and corresponding values of code transition errors are also studied. In addition we have seen the effects of input frequency and number of samples on computation of ENOB.

A. Effect of additive noise, frequency and overdrive on EB

For 5 bit simulated ADC figure 1 and table1 shows the Comparative Graphical representation of effect of input frequency (0.5 to 35 MHz) on computation of ENOB, with Sampling frequency = 5 MHz, no. of samples = 30,000, ENOB with ideal $V_{\min} = 4.386546$ was constant for input freq. Figure 2 & table 2 present the effects of number of samples (128 to 32,000) on Computation of ENOB considering, Sampling frequency = 5 MHz, signal frequency = 0.98 MHz, ENOB with ideal $V_{\min} = 4.386546$ was constant. In addition we have studied the effects of overdrive and additive noise on estimation of ENOB with applying correction. EB are computed for different values of additive noise standard deviation and overdrive, figure 3 and 4 shows the results. Results have been compared with earlier published work and verified the present work with better improvemen.

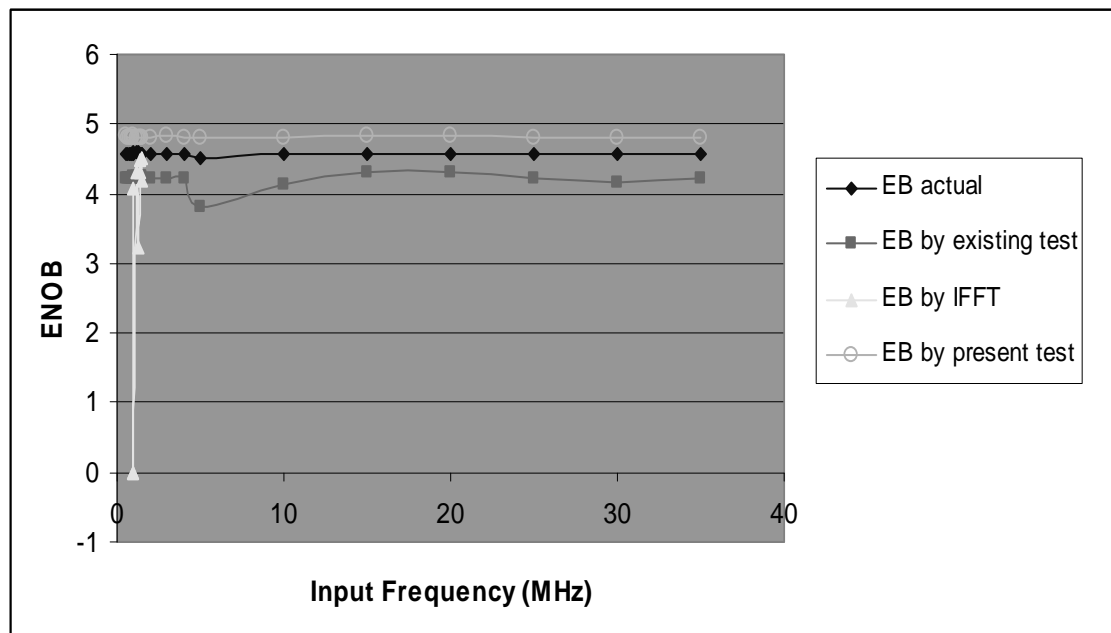


Figure 1: Comparative Graphical representation of effect of input frequency variation (0.5 to 35 MHz) on computation of ENOB, considering number of bit = 5, Sampling frequency = 5 MHz, no. of samples = 30,000, ENOB with ideal $V_{\min} = 4.386546$ is constant for input freq.

Table 1: Comparative representation of effect of input frequency variation on computation of ENOB, considering number of bit = 5, Sampling frequency = 5 MHz, no. of samples = 30,000, ENOB with ideal $V_{\min} = 4.386546$ is constant for Input freq. 0.5 to 35 MHz.

Input frequency (MHz)	Sampling Frequency (MHz)	Actual ENOB	ENOB with existing method [10]	ENOB by IFFT with $f_s = 25$ MHz[5]	ENOB by present method after applying correction
0.5	5.0	4.573734	4.228249	-	4.819966
0.6	5.0	4.572649	4.227511	-	4.817737
0.7	5.0	4.573159	4.229524	-	4.8178883
0.8	5.0	4.572006	4.227579	-	4.818321
0.90	5.0	4.572592	4.226966	-	4.817588
0.95	5.0	4.572876	4.227699	4.064257	4.817079
0.98	5.0	4.573169	4.229539	-	4.818908
1.0	5.0	4.596895	4.250620	-	4.815631
1.15	5.0	4.598831	4.243457	4.304283	4.815850
1.25	5.0	4.589632	4.233557	3.238241	4.815785
1.35	5.0	4.579893	4.233852	4.307919	4.815990
1.40	5.0	4.581024	4.238421	4.476114	4.815899
1.45	5.0	4.579934	4.239912	4.525753	4.815999
1.47	5.0	4.582243	4.239822	4.200557	4.816188
2.0	5.0	4.578288	4.233373	-	4.816766
3.0	5.0	4.565704	4.223096	-	4.819123
4.0	5.0	4.565250	4.220376	-	4.818283
5.0	5.0	4.517232	3.810896	-	4.793368
10.0	5.0	4.567036	4.132831	-	4.813971
15.0	5.0	4.581117	4.313170	-	4.821670
20.0	5.0	4.575615	4.303790	-	4.825302
25.0	5.0	4.570165	4.209352	-	4.814118
30.0	5.0	4.567893	4.160155	-	4.816209
35.0	5.0	4.572742	4.213235	-	4.817036

Table 2: Comparative ENOB representation with number of bit = 5, Sampling frequency = 5 MHz, signal frequency = 0.98 MHz, considering variations in number of samples. ENOB with ideal $V_{min} = 4.386546$ is constant for number of samples 128 to 32,000.

N0. of samples	Actual ENOB	ENOB with ref. [10]	ENOB by SWCF method [7]	ENOB by Hist. ref.[12]	ENOB with (Hist. + Best Fit.) [13]	ENOB by present method with corrections
128	4.185360	3.130298	4.200661 with 256 samples	-	-	4.735163
512	4.556911	4.108856	4.855707	4.393888	4.597796	4.797044
1024	4.550610	4.119329	4.685557	4.341025	4.607100	4.804750
2048	4.562847	4.156365	4.337024	4.361735	4.607080	4.815436
4096	4.572277	4.236417	4.502785	4.359600	4.604679	4.816887
10,000	4.573724	4.237889	4.311685 with 8192 samples	4.332037	-	4.818344
12,000	4.573800	4.236616	-	4.332037 with 8192 samples	4.604537 with 8192 samples	4.818835
15,000	4.572532	4.232130	-	-	-	4.818433
20,000	4.572081	4.226139	-	4.341084 with 16384 samples	4.605245 with 16384 samples	4.817811
25,000	4.572741	4.224588	-	-	-	4.818108
27,000	4.572330	4.223969	-	-	-	4.818245
30,000	4.572673	4.224141	-	4.340817	4.606943	4.818024
31,000	4.572534	4.224272	-	-	-	4.817864
32,000	4.572909	4.224811	-	-	-	4.817984

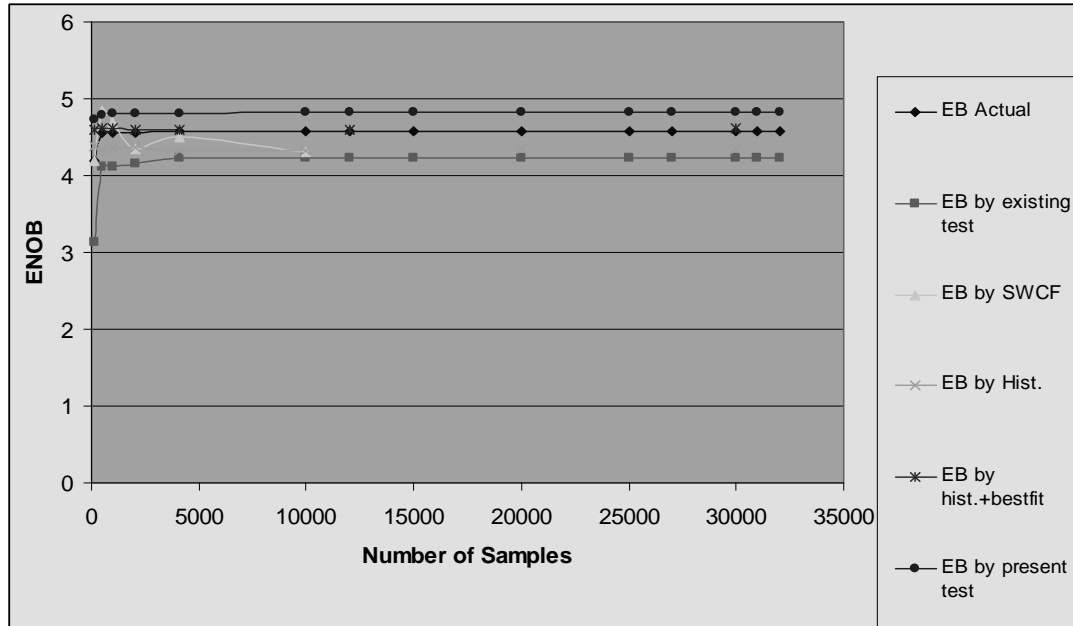


Figure 2: Comparative ENOB Graphical representation with number of bit = 5, Sampling frequency = 5 MHz, signal frequency = 0.98 MHz, considering variations in number of samples. ENOB with ideal $V_{min} = 4.386546$ is constant for number of samples 128 to 32,000.

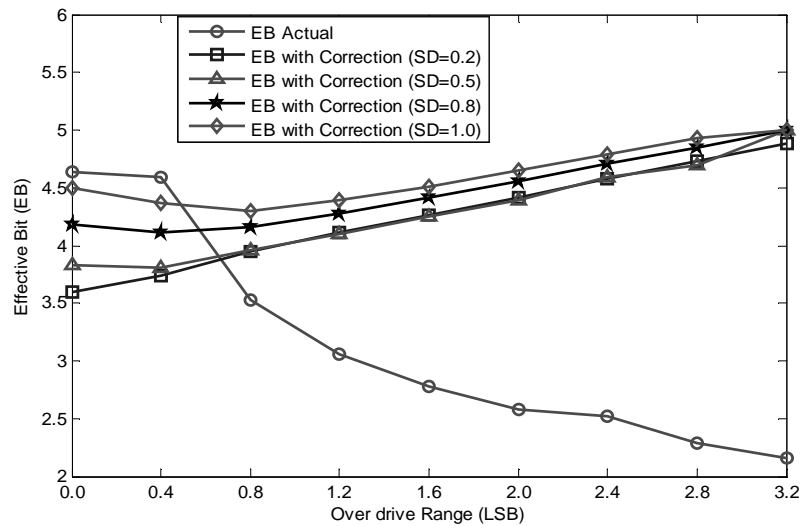


Figure 3: Comparative graphical representation of over drive and standard deviation effects on EB after applying correction

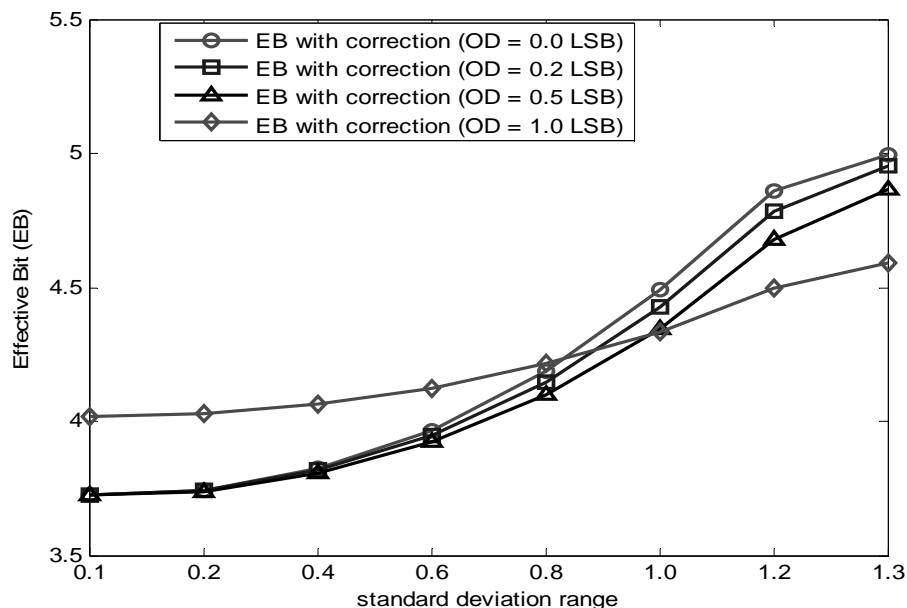


Figure 4: Comparative graphical representation of standard deviation effects on EB applying correction with fixed over drive.

Conclusion

In this paper effect of overdrive, frequency, samples and error in transition voltage on effective bits have been studied. Mean of normalized transition voltage is calculated and error in normalized transition voltage is computed by taking difference from estimated transition voltages. Error in values of ENOB in presence of additive noise is determined with different amount of overdrive. ENOB is determined by taking deviation of actual rms error from best fit (ideal) rms error of ADC transfer characteristics. Simulation results are reported for five bit ADC by taking large number of samples of full scale sine wave at input test frequency and sampling frequency. Comparative results are reported with better improvement in comparison of earlier published work. This work will be useful for testing A/D converter from device manufacturer point of view as well as circuit designer. A test algorithm developed using simulation is equally suitable for testing real life ADC in application conditions.

Acknowledgment

This work has been carried out in SMDP VLSI laboratory of the Electronics and Instrumentation Engineering Department of Shri G S Institute of Technology and Science, Indore, India. This SMDP VLSI project is funded by Ministry of Information and Communication Technology, Government of India. Authors are thankful to the Ministry for facilities provided under this project.

References

- [1] Hsin-Wen Ting, Bin-Da Liu and Soon-Jyh Chang, “ A Histogram Based Testing Method for Estimating A/D Converter Performance” *IEEE transaction on Instrumentation and measurement*, vol 57, No 2, Feb 2008.
- [2] F. Correa Algria and A. Cruz Serra, “Standared Histogram Test Precision of ADC gain and offset error estimation” *IEEE transaction on instrumentation and measurement*, vol 56, No 5, October, 2007.
- [3] D. K. Mishra and R. S. Gamad, “Determination of Non linearity and effective resolution of an A/D converter for arbitrary application input” international conf. on circuits and systems, San *Francisco*, USA 24-26, OCT. 2007, pp 220-223.
- [4] D. K. Mishra and R. S. Gamad, “Estimation of error in nonlinearity in ADC using histogram technique” international conf. on circuits and systems, San *Francisco*, USA 22-24, OCT. 2008, pp 185-188.
- [5] F Correa Algeria and A Cruz Serra, “Error in the estimation of transition voltages with the standard histogram test ADCs” *ELSEVIER international Journal on Measurement*, 35 (2004), pp 389-397.
- [6] D. K. Mishra, ADC testing using interpolated Fast Fourier transform (IFFT) technique, *International Journal of Electronics, Taylor and Francis*, Vol. 90, no. 7, 2003, PP. 459- 469.
- [7] D K Mishra, “Some Methods for Dynamic Testing of A/D Converters” Ph. D. Thesis, May 2000, DAVV University Indore.
- [8] D K Mishra, Dynamic testing of high speed A/D converters using triangular Wave as input test signal, *IE (I) Journal-ET-2005*, Vol 85, January 2005, pp 68-71.
- [9] Jerome Blair, “Histogram measurement of ADC nonlinearity using sine waves”, *IEEE transaction on instrumentation and measurement*, Vol 43, no 3, June 1994, , PP 378-383.
- [10] M F Wagdy & Selim Awad, Determining ADC effective number of bits via Histogram testing, *IEEE transaction on instrumentation and measurement*, vol 40, no 4, august 1991.
- [11] IEEE std- 1057-1994, “IEEE standard for digitizing waveform recorders”.
- [12] D K Mishra, N S Choudhary and M C Shrivastava, “ Dynamic testing of an ADC by Least square error minimization in Histogram technique,” *Electrical division of Journal of intitute of Engineers (India)*, vol 78, May 1997, pp 31-35.
- [13] D K Mishra, M C Shrivastava and N S Choudhary, “ New Dynamic test methods for determination on nonlinearity and effective resolution of A/D converters”*Indian Institute of Electronics and Telecommunication Engineers(India)*, *Journal of Research* vol 43,no 6, Nov.-Dec. 1997, pp 403-409.

