

EE 230

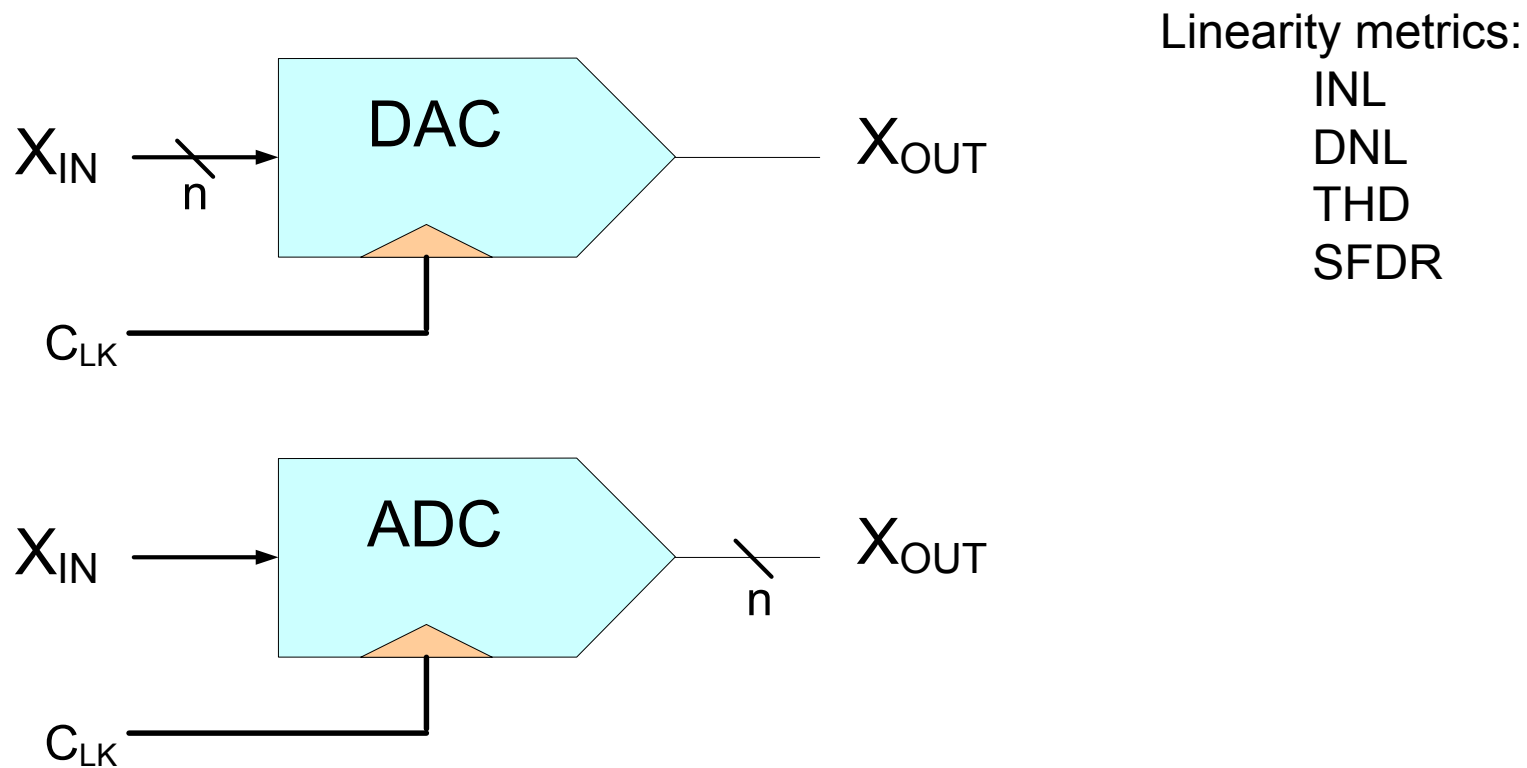
Lecture 44

Data Converters

Nonideal Effects

Review from Last Time:

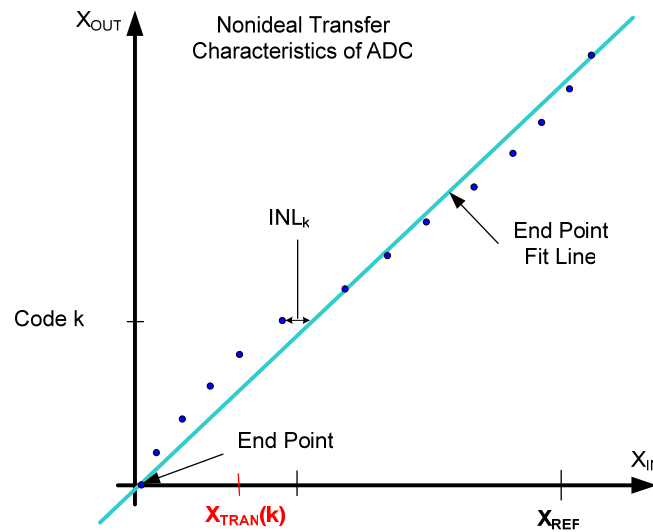
Characterization of Nonlinearities



Linearity Metrics for ADC and DAC are Analogous to Each Other

Review from Last Time:

Integral Nonlinearity (INL)



Linearity metrics:
→ INL
DNL
THD
SFDR

$$INL_k = X_{TRAN}(k) - X_{FIT}(k)$$

$$INL = \max_{1 \leq k \leq N} \{|INL_k|\}$$

$$INL_{LSB} = \frac{INL}{X_{LSBF}}$$

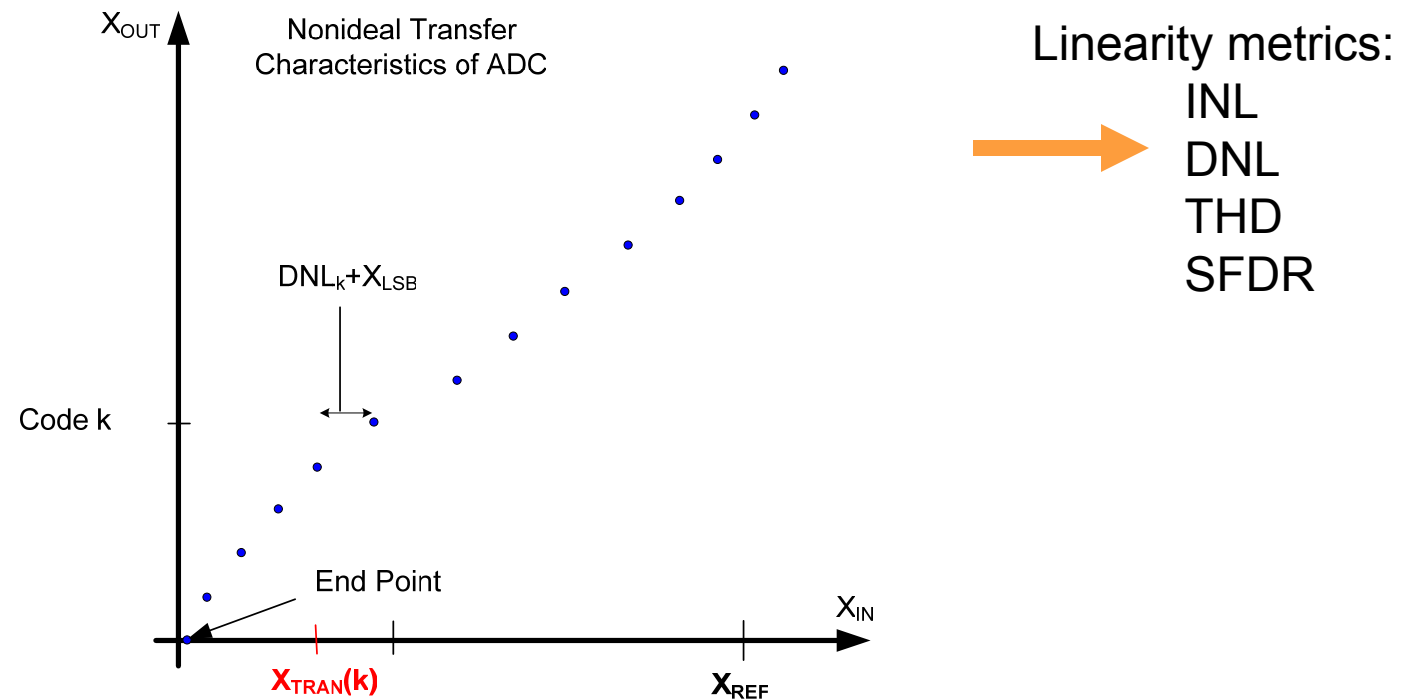


$$INL_{LSB} \cong 2^n \frac{INL}{X_{REF}}$$

INL of an ideal ADC is 0

Review from Last Time:

Differential Nonlinearity (DNL)

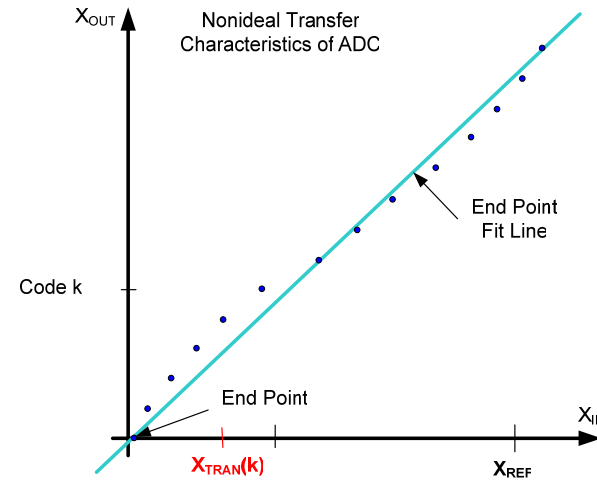
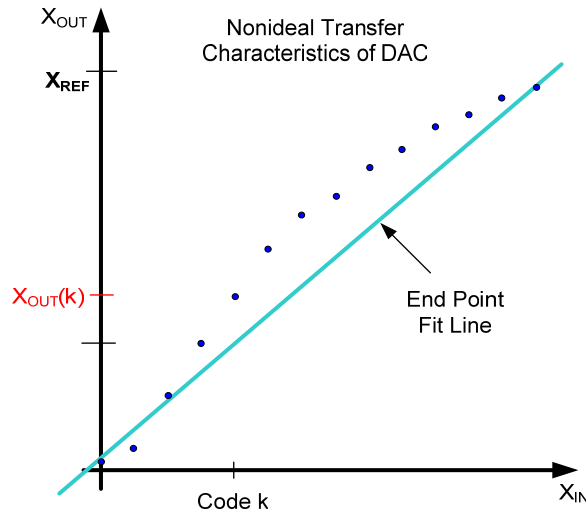


$$DNL_k \cong X_{TRANS}(k) - X_{TRANS}(k-1) - X_{LSB}$$

$$DNL = \max_{1 < k \leq N} \{ |DNL_k| \}$$

Review from Last Time:

Equivalent Number of Bits -ENOB (based upon linearity)



If v is the INL in LSB

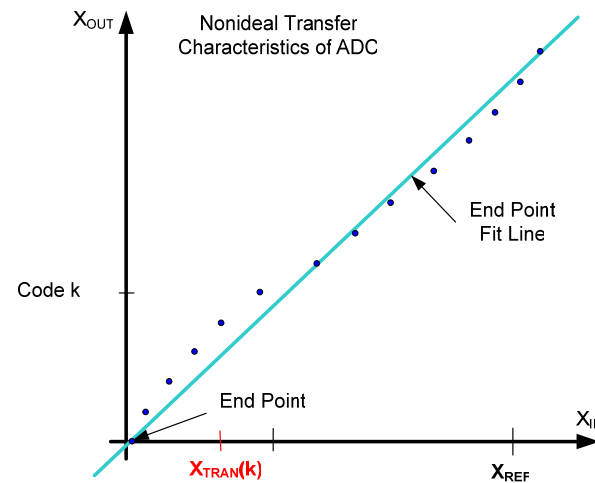
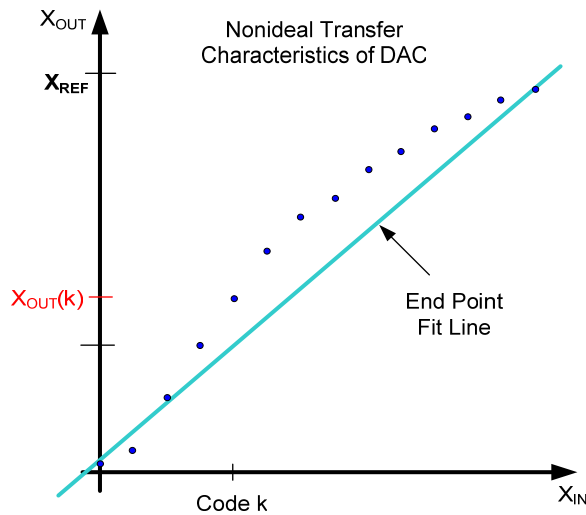
$$ENOB = n-1 - \frac{\log_{10} v}{\log_{10} 2}$$

v res

0.5	n
1	$n-1$
2	$n-2$
4	$n-3$
8	$n-4$
16	$n-5$

Review from Last Time:

Spectral Characterization



Linearity metrics:

INL

DNL

THD

SFDR

INL and DNL do not give a good indicator of linearity of a data converter in some (many) applications

THD and SFDR are alternate ways to characterize the linearity of a data converter

Review from Last Time:

Spectral Characterization

$$X_{IN} = X_M \sin(\omega t + \theta)$$

$$X_{OUT} = A_0 + A_1 \sin(\omega t + \theta + \gamma_1) + \sum_{k=2}^{\infty} A_k \sin(k\omega t + \theta + \gamma_k)$$

A_k , $k > 1$ are all spectral distortion components

Generally only first few terms are large enough to represent significant distortion

$$THD = \frac{\sum_{k=2}^{\infty} A_k^2}{A_1^2}$$

$$THD_{dB} = 10 \log_{10} \left(\frac{\sum_{k=2}^{\infty} A_k^2}{A_1^2} \right)$$

$$SFDR = \frac{|A_1|}{\max_{1 < k} \{|A_k|\}}$$

$$SFDR_{dB} = 20 \log_{10} \left(\frac{|A_1|}{\max_{1 < k} \{|A_k|\}} \right)$$

Review from Last Time:

Spectral Characterization

$$X_{IN} = X_M \sin(\omega t + \theta)$$

$$X_{OUT} = A_0 + A_1 \sin(\omega t + \theta + \gamma_1) + \sum_{k=2}^{\infty} A_k \sin(k\omega t + \theta + \gamma_k)$$

Key theorem useful for spectral characterization

Theorem: If a periodic signal $x(t)$ with period $T=1/f$ is band-limited to frequency hf and if the signal is sampled N times over an integral number of periods, N_P , then

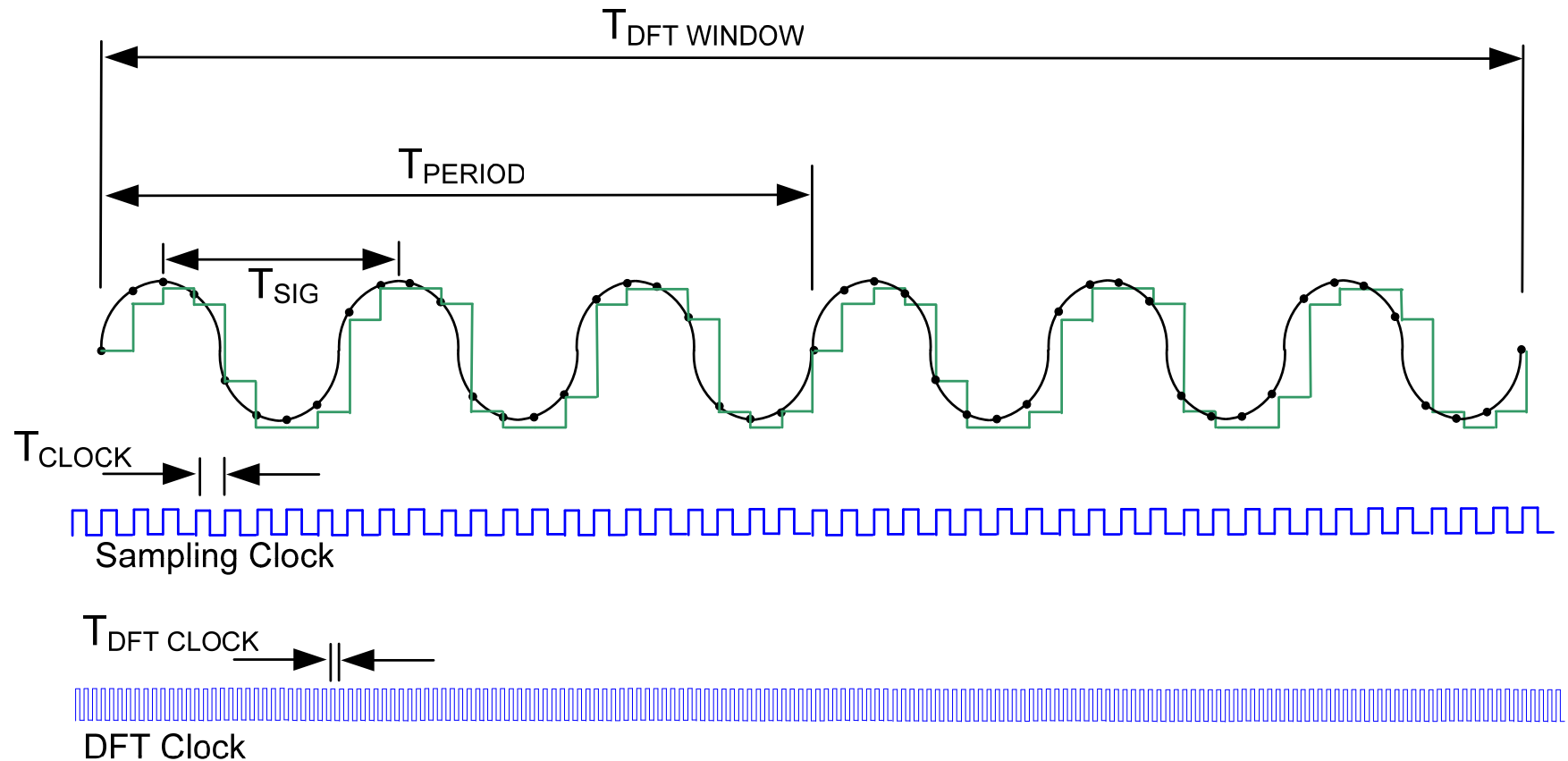
$$|A_m| = \frac{2}{N} |X(mN_P + 1)| \quad \text{for } 0 \leq m \leq h-1$$

where $\langle X(k) \rangle_{k=1}^{N-1}$ is the DFT of the sampled sequence $\langle x(kT_S) \rangle_{k=1}^{N-1}$ where T_S is the sampling period.

$$T_S = \frac{T \cdot N_P}{N}$$

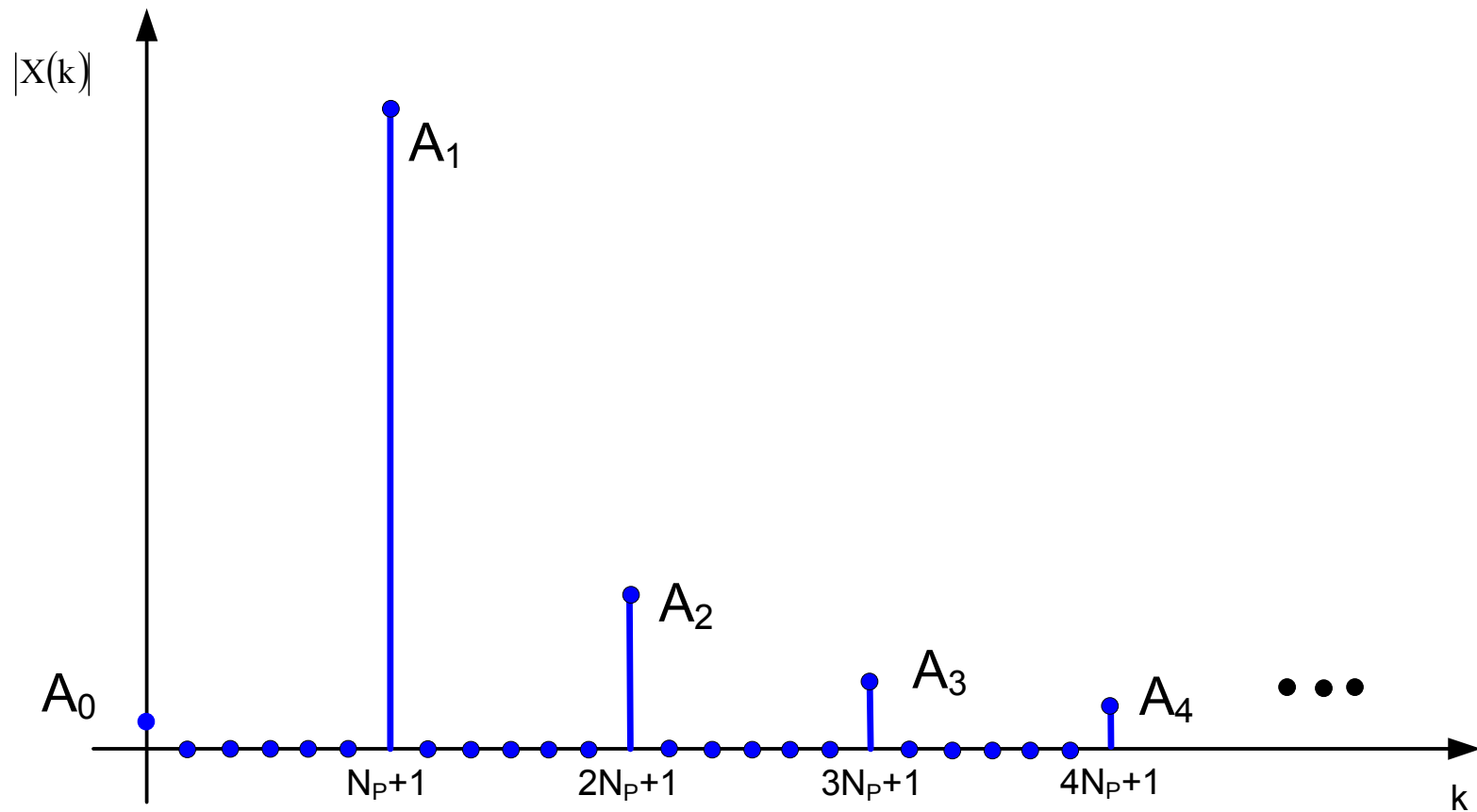
Review from Last Time:

Spectral Characterization



Review from Last Time:

Spectral Characterization



Engineering Issues for Using Data Converters

1. Inherent with Data Conversion Process

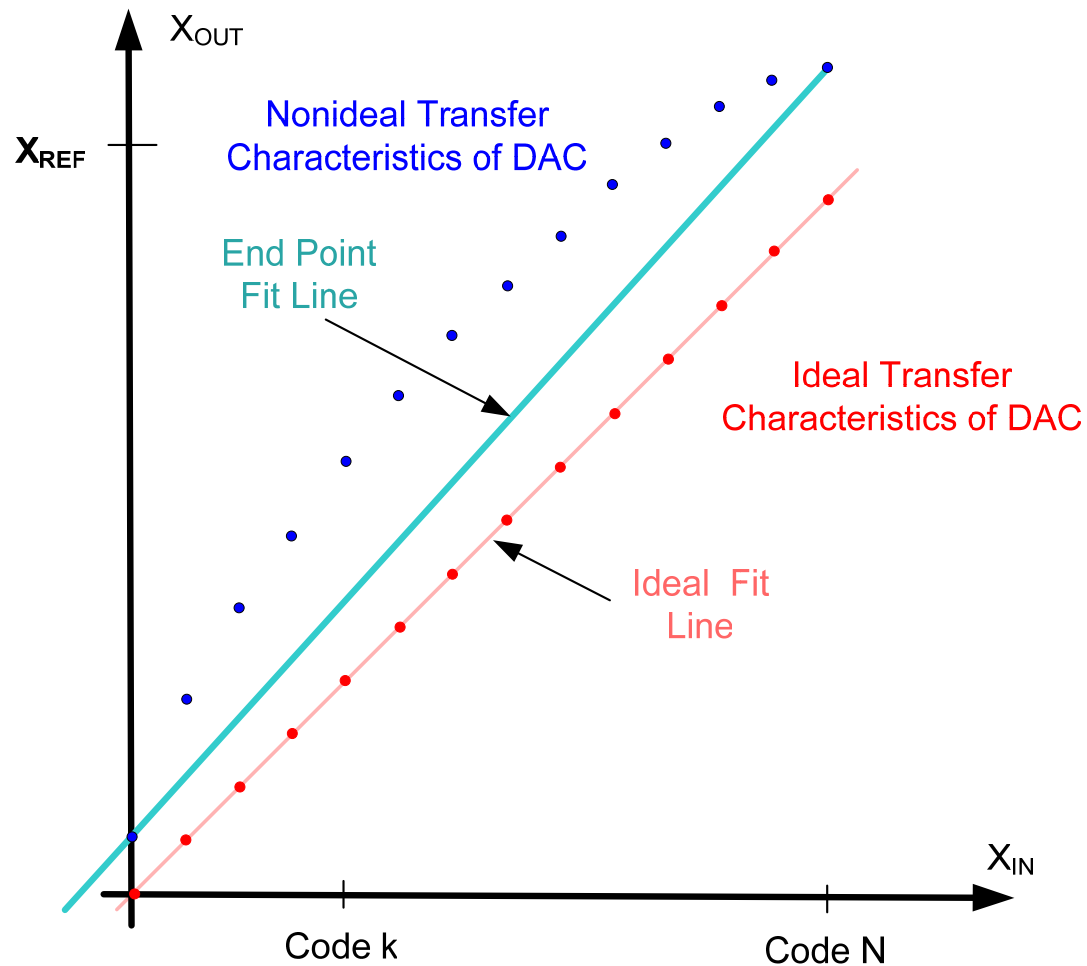
- Amplitude Quantization
 - Time Quantization
- (Present even with Ideal Data Converters)

2. Nonideal Components

- Uneven steps
 - Offsets
 - Gain errors
 - Response Time
 - Noise
- (Present to some degree in all physical Data Converters)

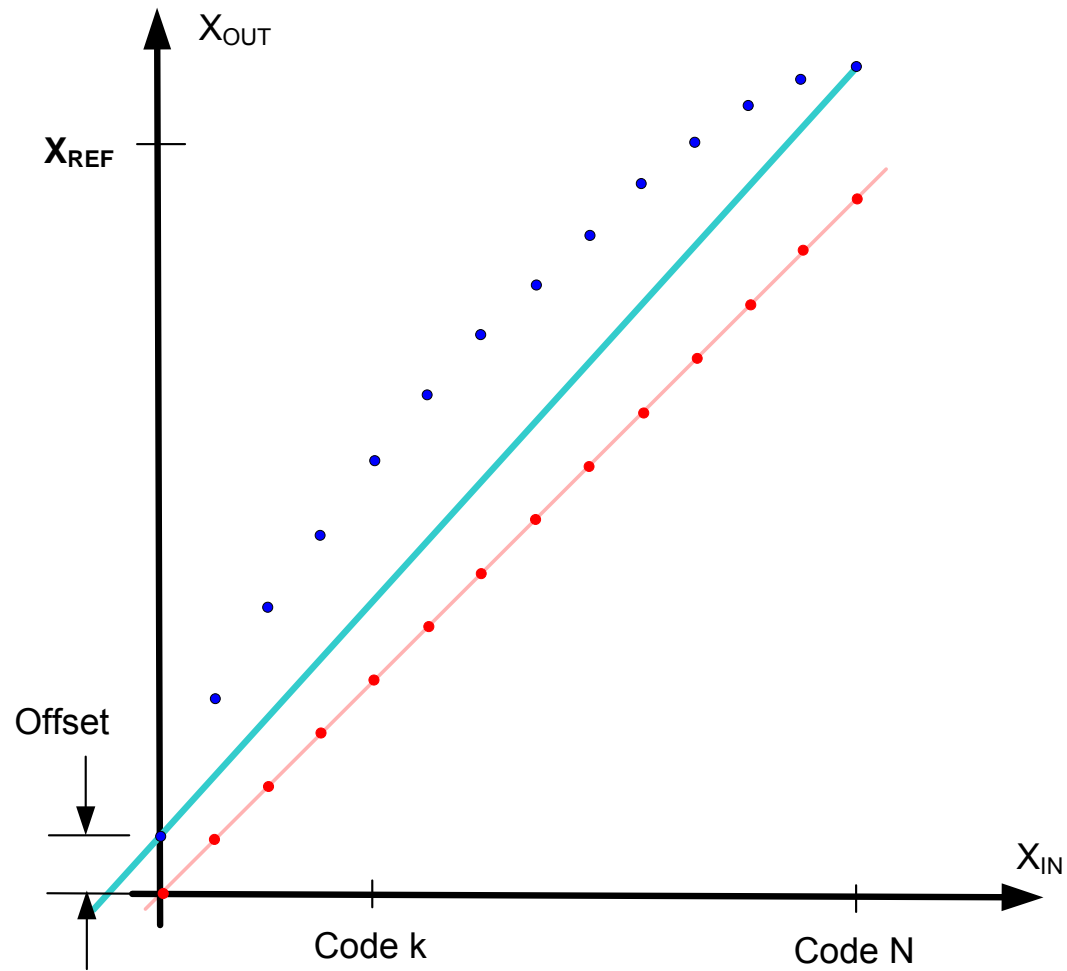
How do these issues ultimately impact performance ?

Offset and Gain Errors

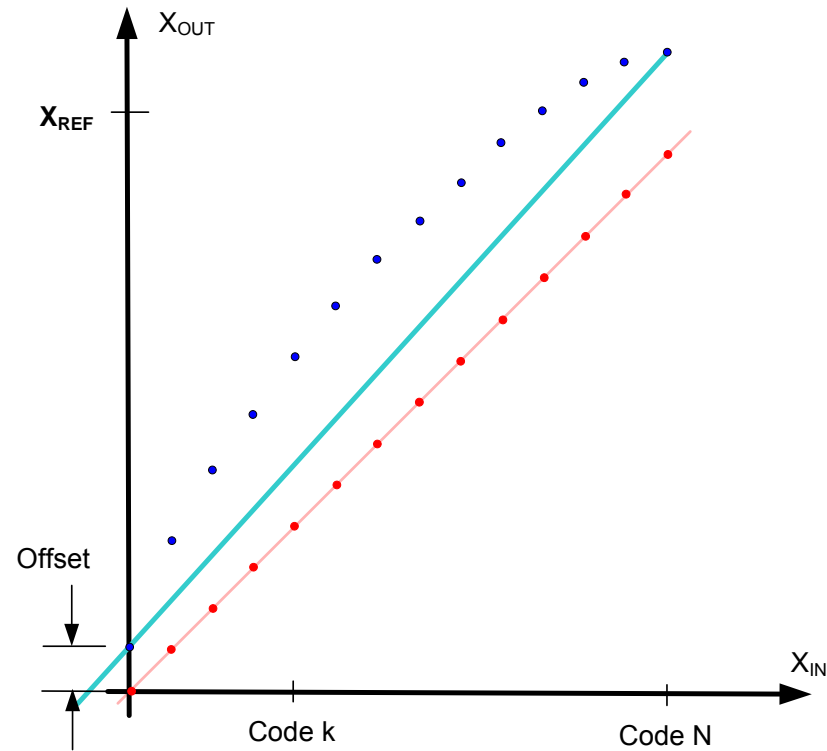


- Fit line is shifted from ideal transfer characteristics and has a different slope
- These deviations are termed “offset” and “gain” errors
- Analogous definitions for ADCs (will not be discussed here)

Offset Errors

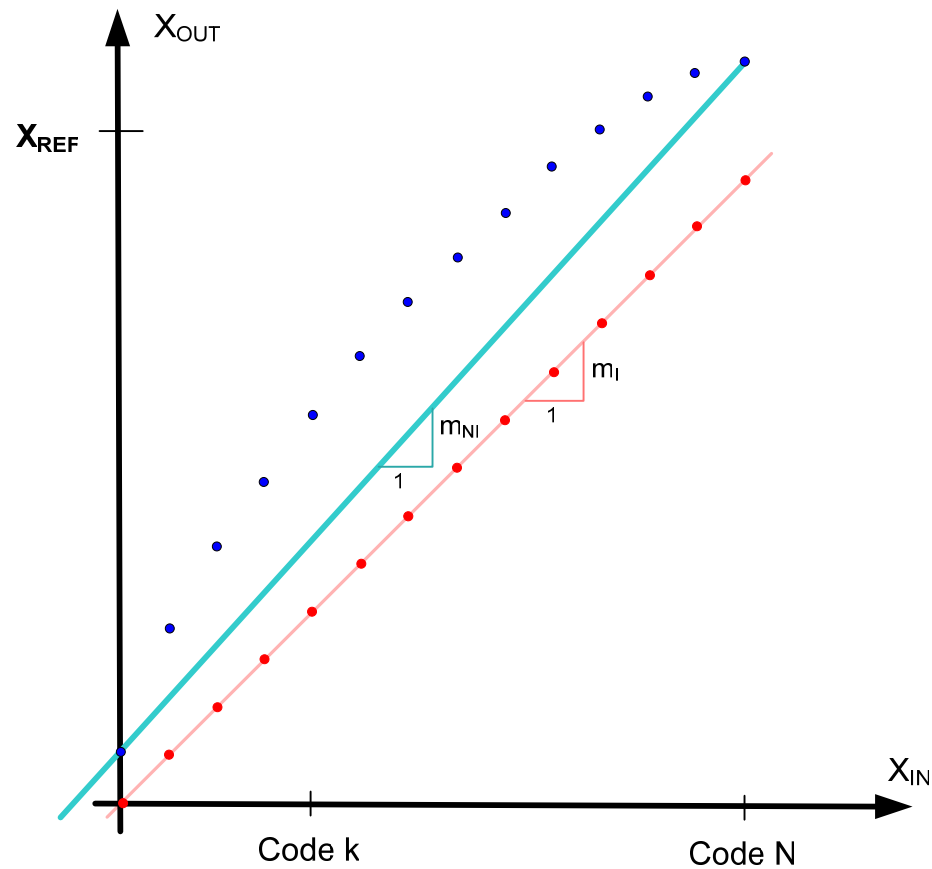


Offset Errors



- Many applications are tolerant to offset errors
- Offset errors can be rather easily calibrated out
- Offset errors require minimal measurement time at test

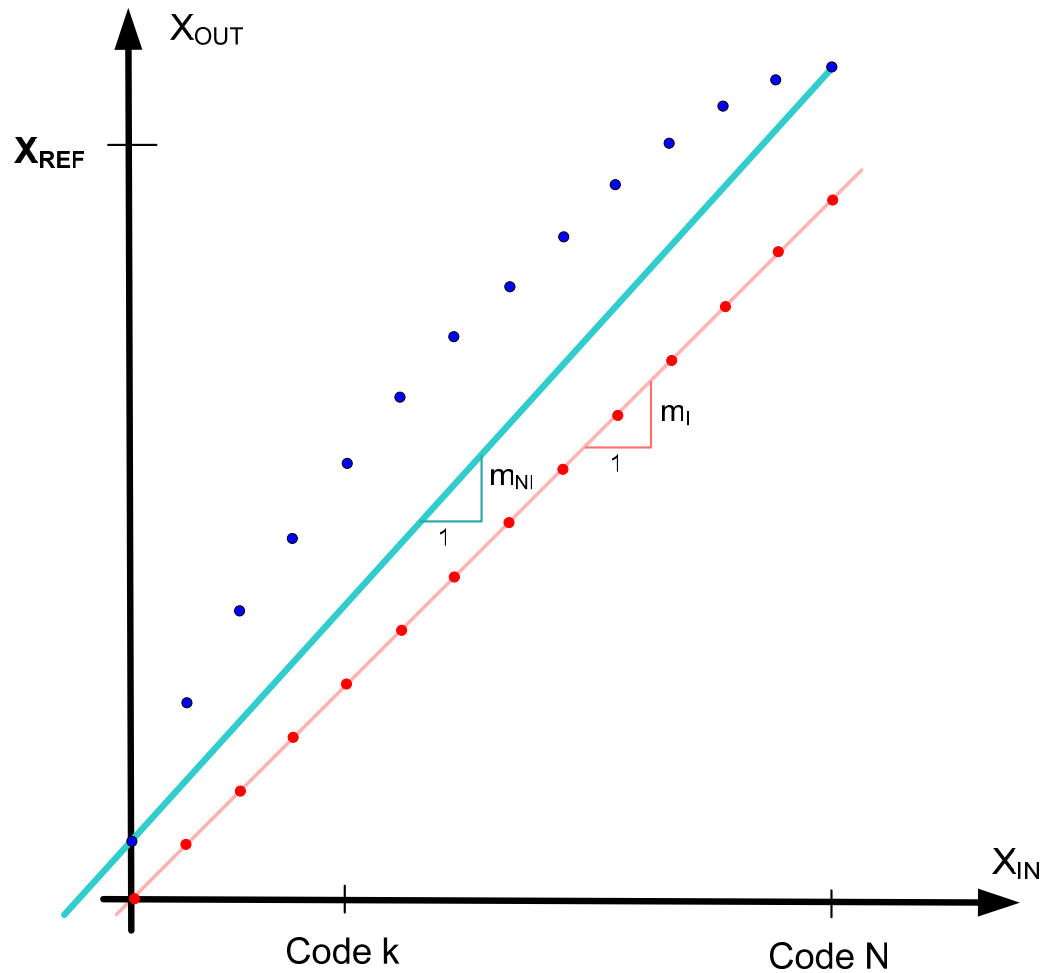
Gain Errors



Gain Error (%):

$$e_{GAIN} = \left[\frac{m_{NI} - m_I}{m_I} \right] \bullet 100\%$$

Gain Errors




- Many applications are tolerant to gain errors
- Gain errors can be rather easily calibrated out
- Gain errors require minimal measurement time at test

Engineering Issues for Using Data Converters

1. Inherent with Data Conversion Process

- Amplitude Quantization
 - Time Quantization
- (Present even with Ideal Data Converters)

2. Nonideal Components

- Uneven steps
- Offsets
- Gain errors
-  Response Time
- Noise

(Present to some degree in all physical Data Converters)

How do these issues ultimately impact performance ?

Response Times

Both ADCs and DACs do not respond instantaneously

Transients due to settling after clock inputs can degrade spectral performance of DAC outputs

The performance of both ADCs and DACs generally degrades as the input signal frequency increases and approaches or exceeds the Nyquist rate

Dominant effect is on degradation of spectral performance (SFDR and THD)
High-frequency SFDR or THD often of major concern when data converters used for high-speed communication applications

Engineering Issues for Using Data Converters

1. Inherent with Data Conversion Process

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2. Nonideal Components

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How do these issues ultimately impact performance ?

Recall: Unwanted signals in the output of a system are called noise.

Distortion

Smooth nonlinearities

Frequency attenuation

Large Abrupt Nonlinearities

Signals coming from other sources

Interference from electrical coupling

Movement of carriers in devices

Interference from radiating sources

Undesired outputs inherent in the data conversion process itself

Noise

Noise sources degrade accuracy of data converters

SNR (Signal to Noise Ratio) and SNDR (Signal to Noise and Distortion Ratio) widely used to characterize noise effects

ENOB relative to noise present due to only quantization effects often used to quantify effects of noise

Noise levels often determine fundamental limits on ability to resolve small signals

Time-averaging can be used to reduce effects of zero-mean random noise if speed requirements of data converter are relaxed

Filtering and shielding can often be used to reduce effects of interference noise

Engineering Issues for Using Data Converters

Nonideal Components

- Uneven steps
- Offsets
- Gain errors
- Response Time
- Noise

In many applications, the major nonideal effects of concern are due to uneven steps in the data converter

Testing time required for INL and DNL measurements is often the dominant contributor to testing time (and cost)

Testing costs at production can be a significant portion of the overall manufacturing costs for some data converters

Final Exam

- Final exam starts at 7:30 a.m. on Monday May 3 and is located in this room
- Exam will be comprehensive but with material since Exam 3 weighted somewhat heavier
- 3 sheets of notes are permitted for the final exam

End of Lecture 44