DATA CONVERTERS

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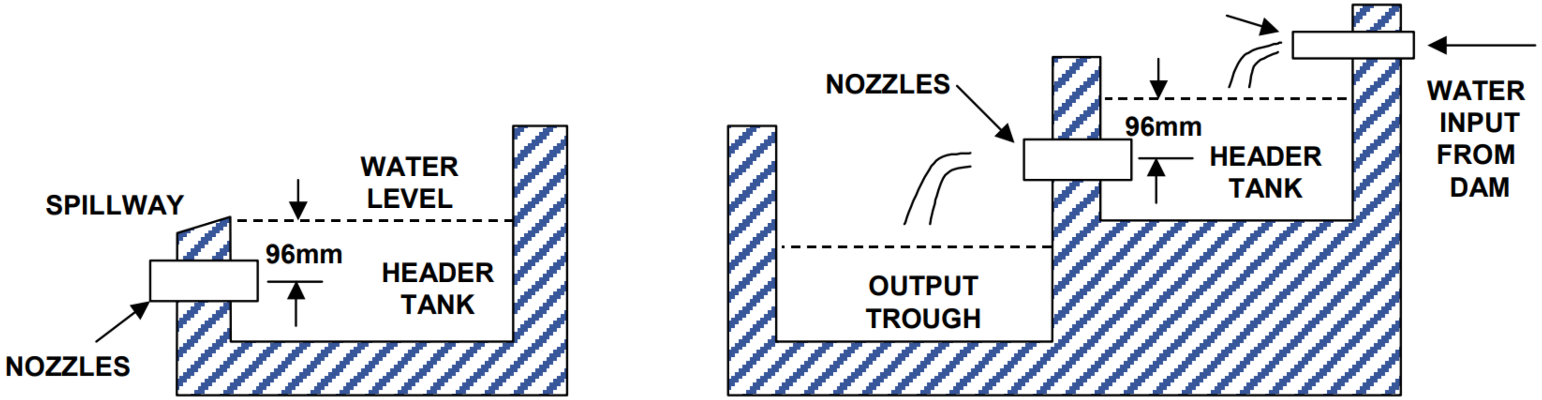
Today's topic

- Historical background on ADC
- Analog to Digital Conversion Process
- Quantization noise & SQNR
- SNDR, SFDR & ENOB

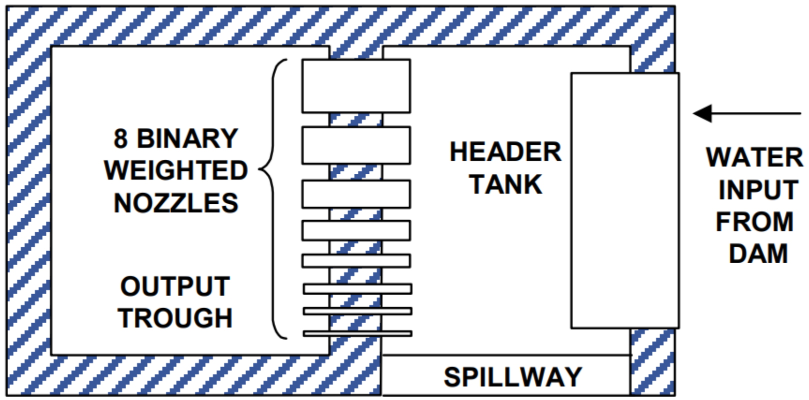
History of Data Converter: 18th Century



(A) HEADER SYSTEM: Note-The spillway and the nozzles need different outlets

(B) SECTIONAL VIEW OF METERING SYSTEM

(C) TOP VIEW OF METERING SYSTEM DETAILS SHOWING BINARY WEIGHTED NOZZLES



Adapted from:
Kâzim Çeçen, "Sinan's Water Supply System in Istanbul," Istanbul Technical University / Istanbul Water and Sewage Administration, Istanbul Turkey, 1992-1993, pp. 165-167.

History of Data Converter: 19th Century

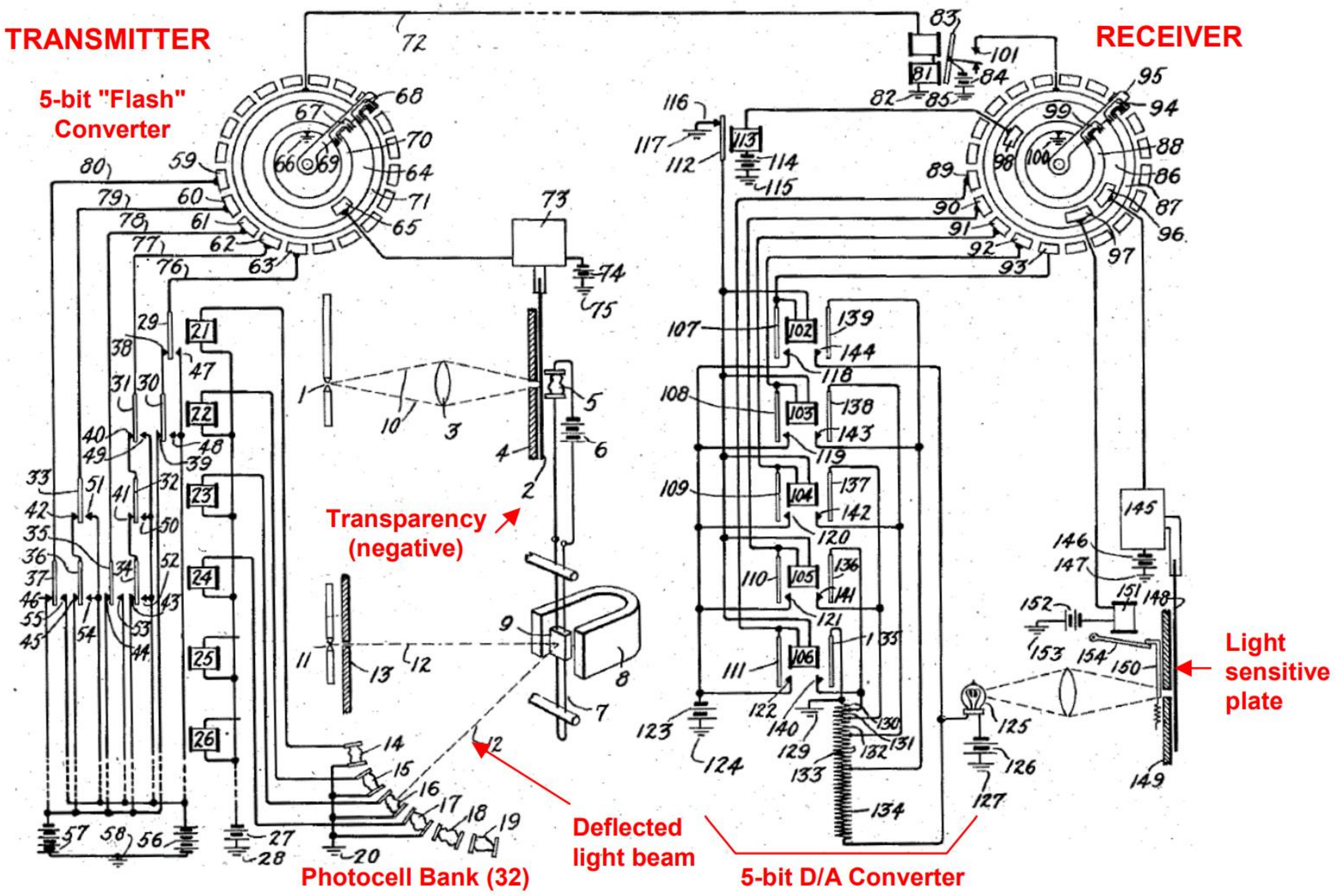
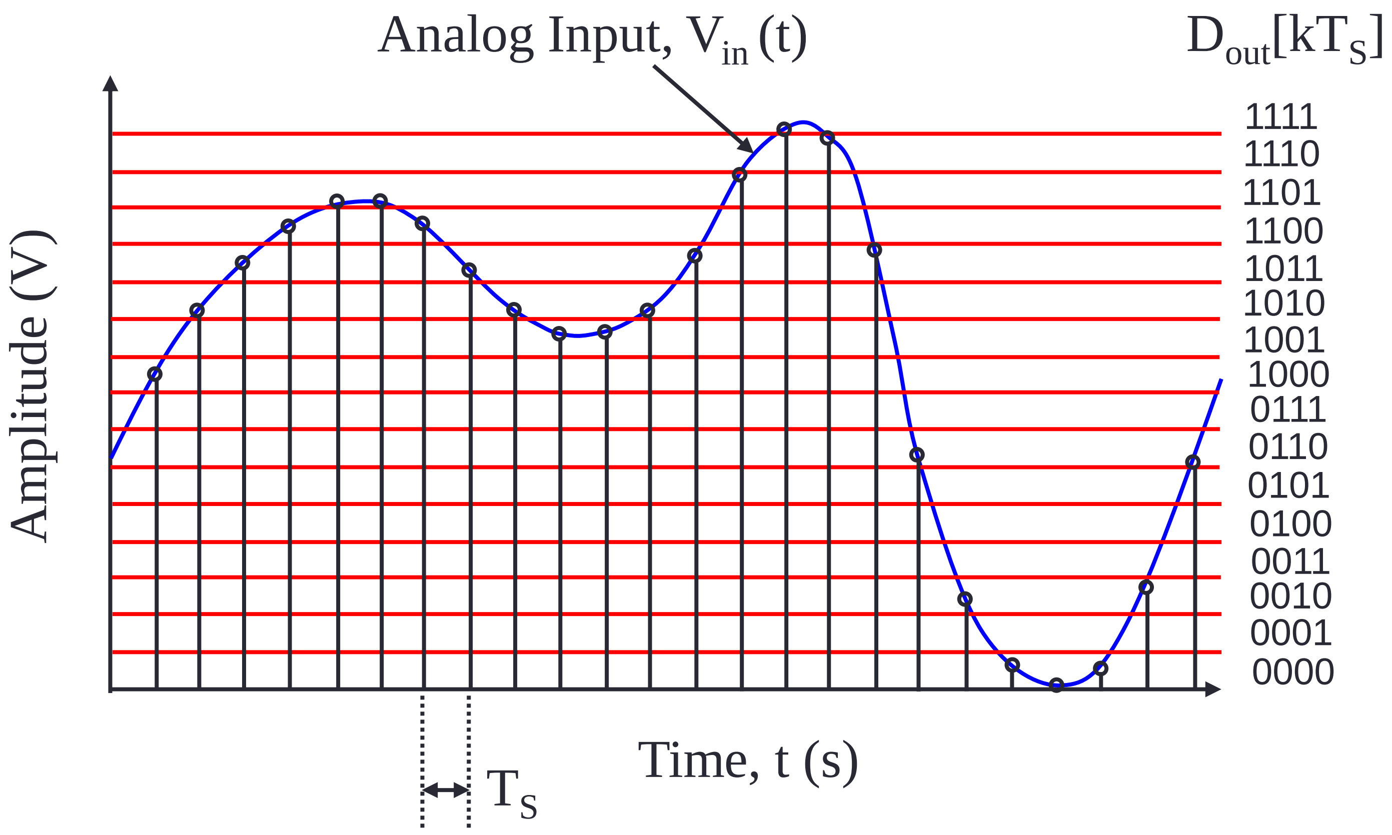
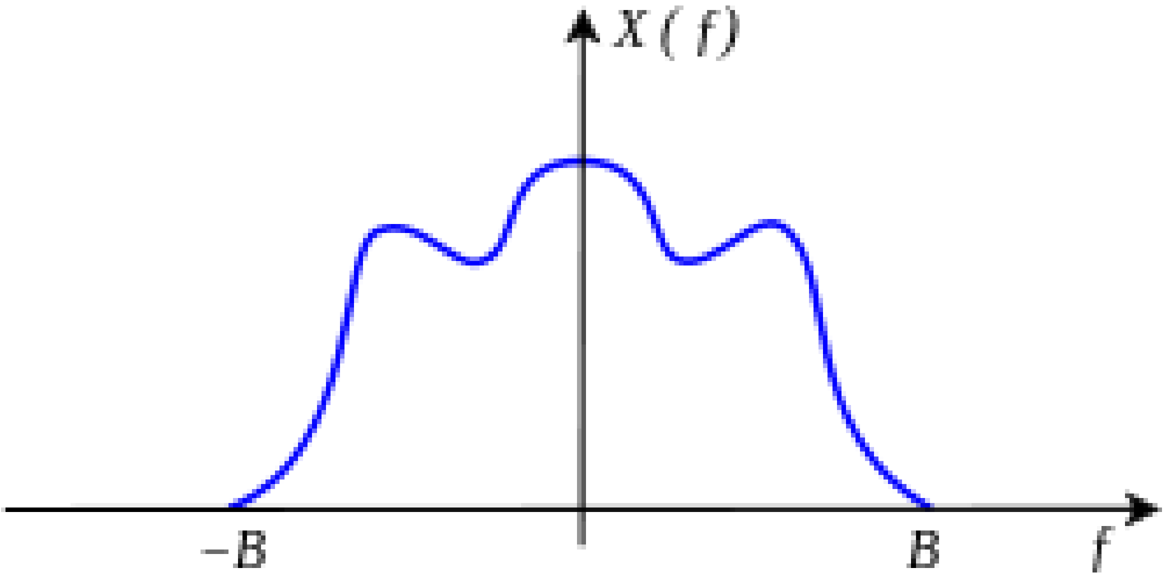


Figure 1.5: *The First Disclosure of PCM: Paul M. Rainey, "Facimile Telegraph System," U.S. Patent 1,608,527, Filed July 20, 1921,Issued November 30, 1926*

Flash Data Converter

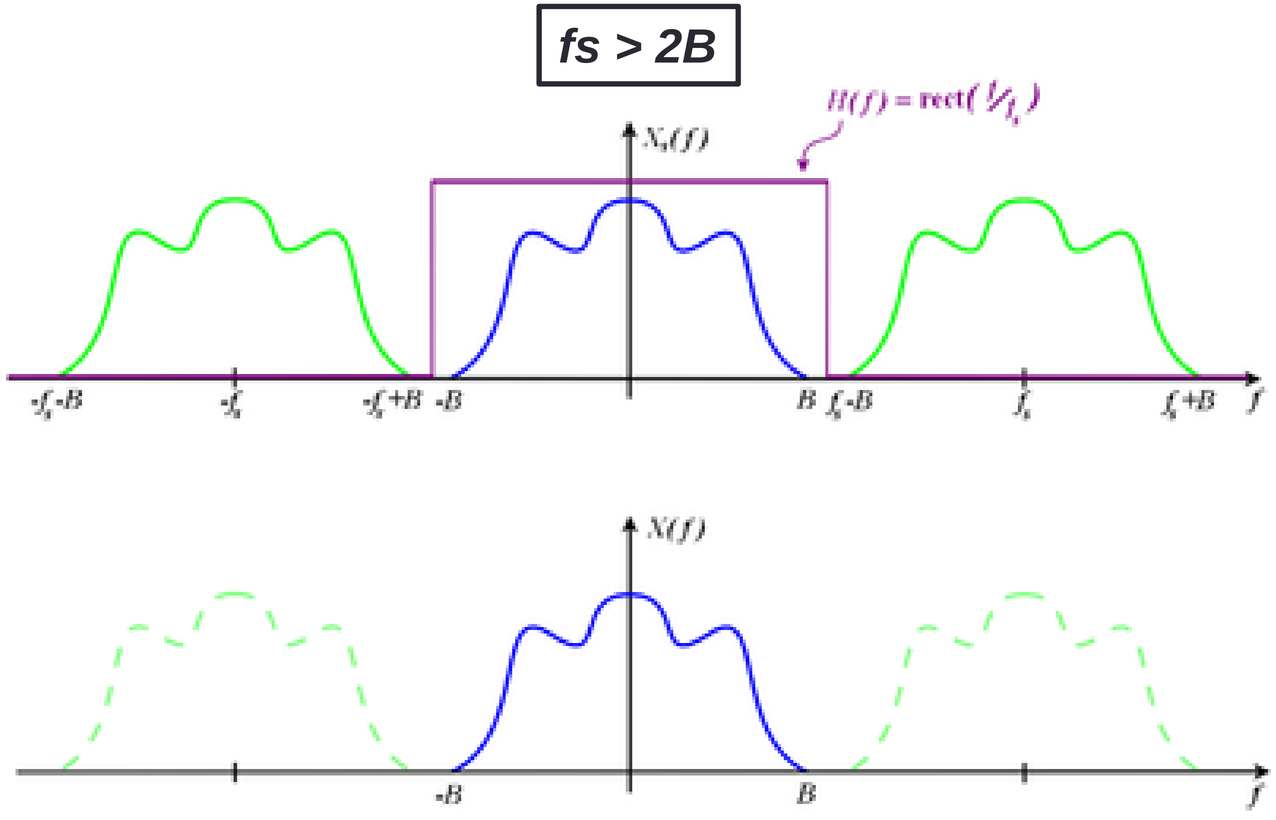


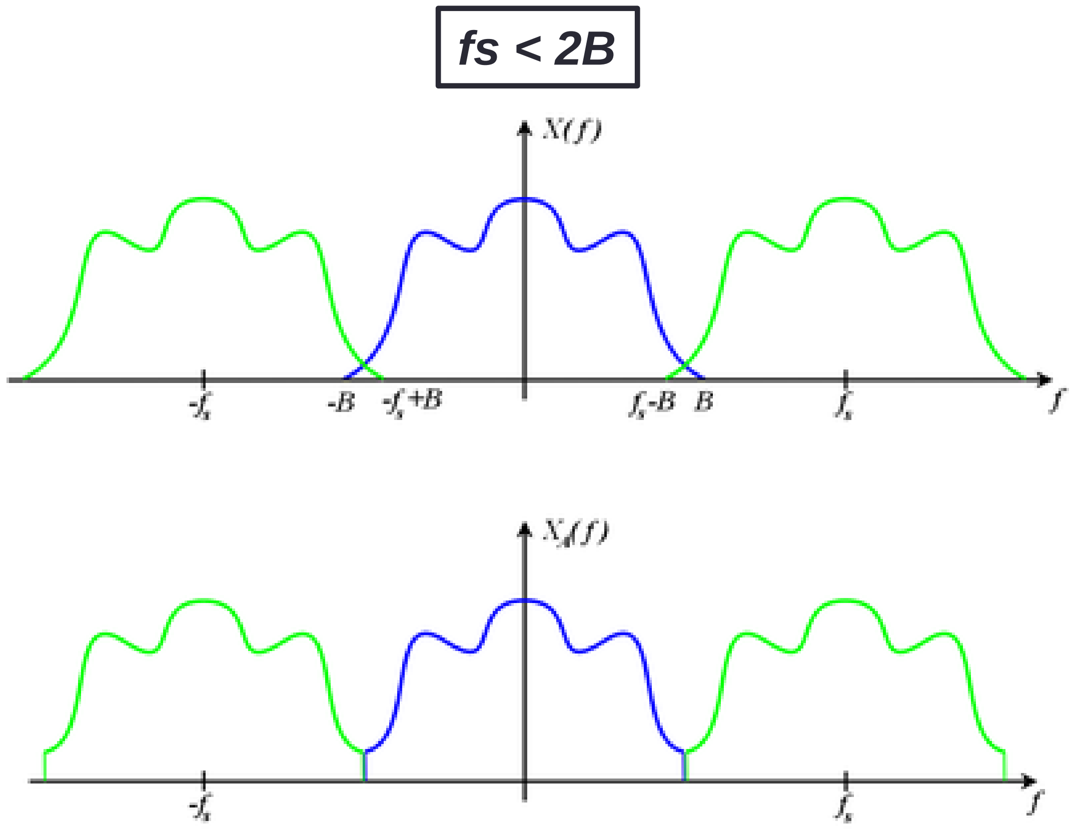
What should be the sampling Rate?



If a Signal has a Bandwidth of *B, a* sufficient sample-rate is 2*B* samples/second, or anything larger. Equivalently, for a given sample rate f_s, perfect reconstruction is guaranteed possible for a bandlimit $B < f_s/2$

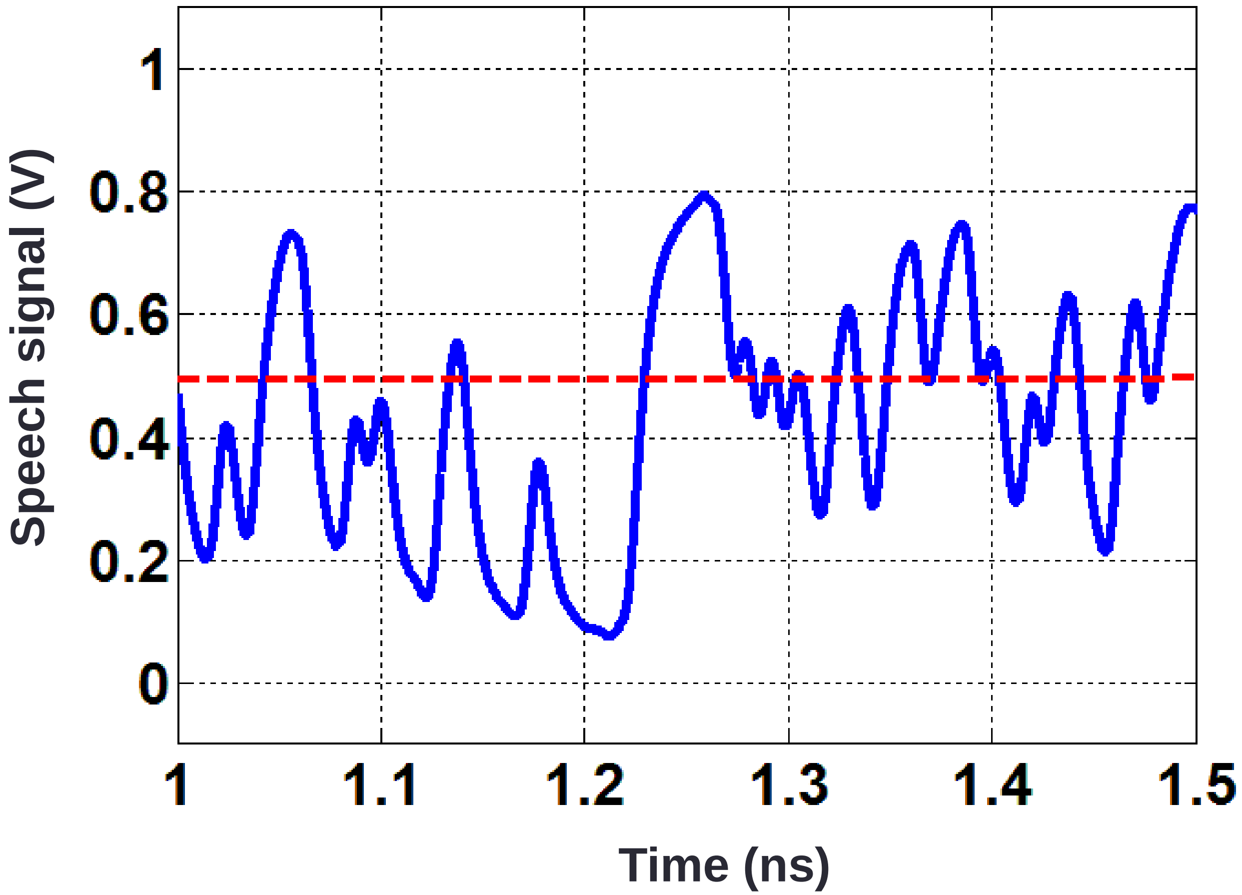
Nyquist Sampling Theorem





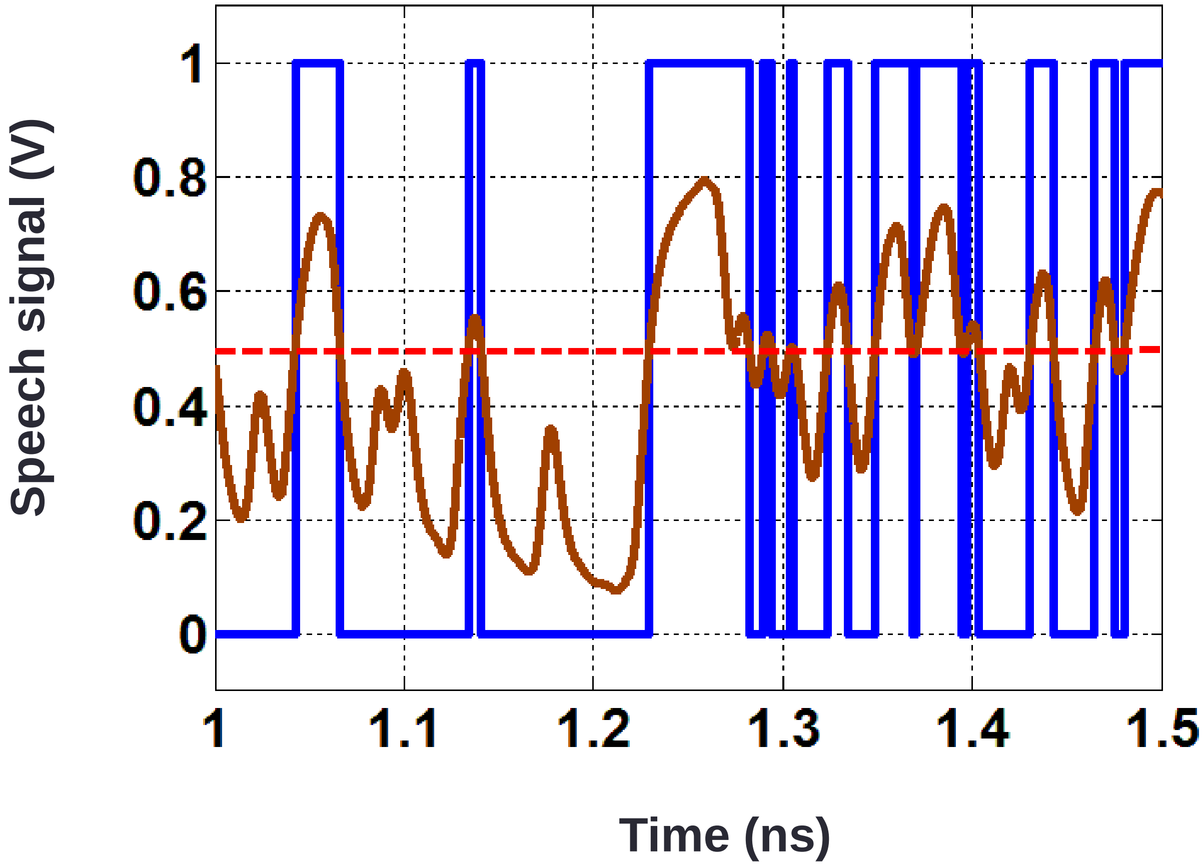
Analog to Digital

To digitize an analog signal we need to set a ‘threshold’ → 0.5 in this case

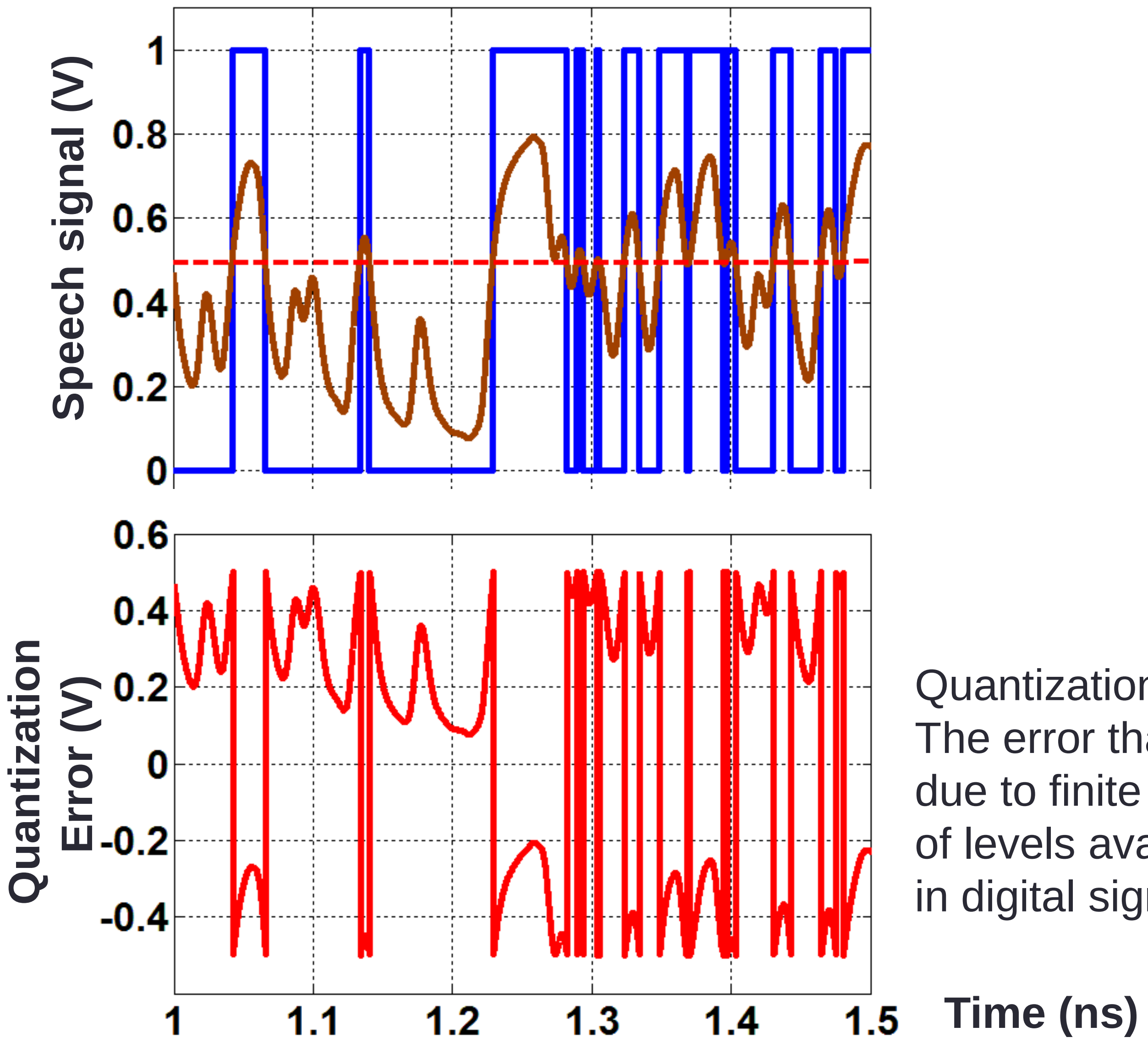


Analog to Digital with 1 bit Quantizer

If signal is <u>above</u> 0.5 → digital output '1'
If signal is <u>below</u> 0.5 → digital output '0'

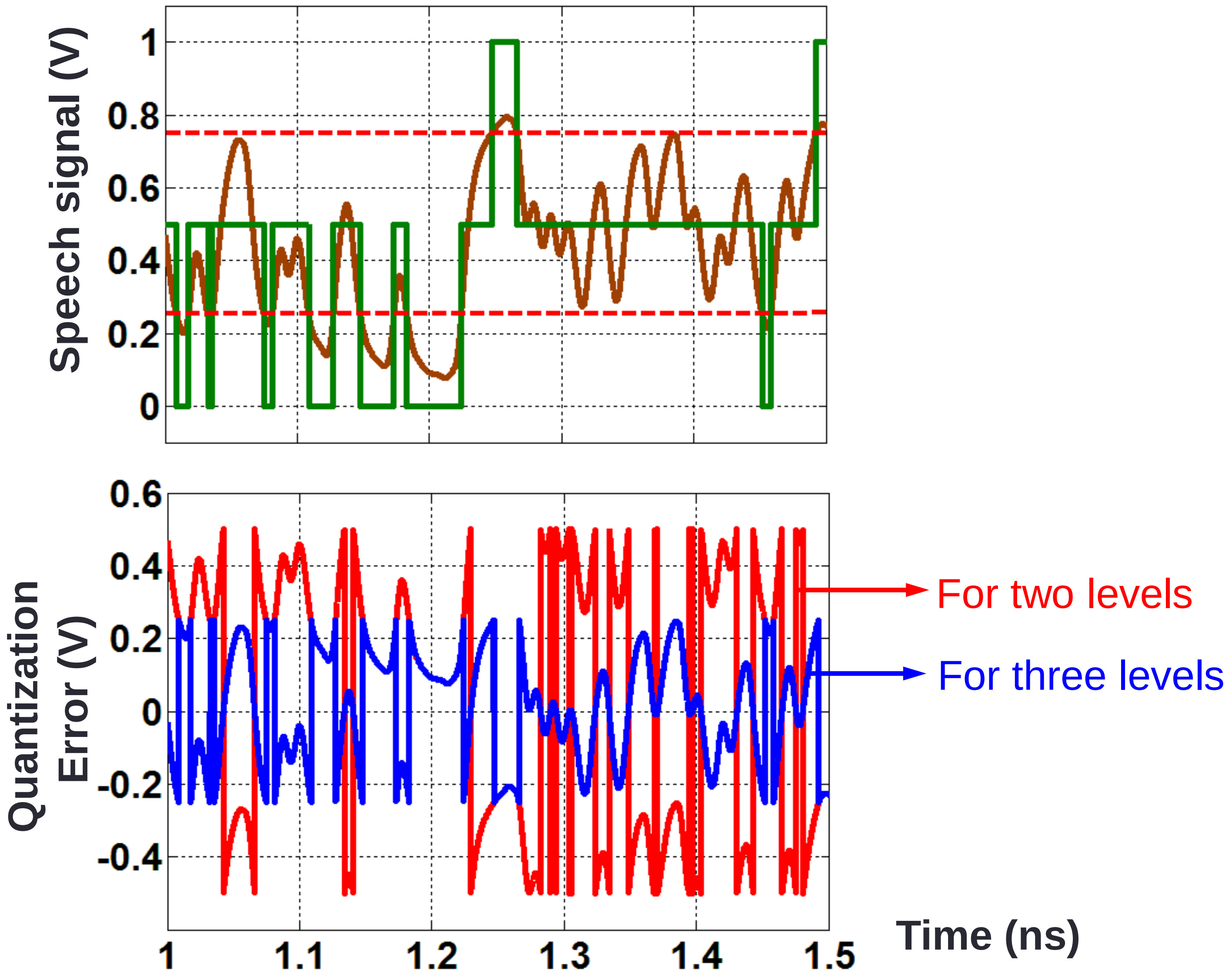


Quantization Noise is Digital system

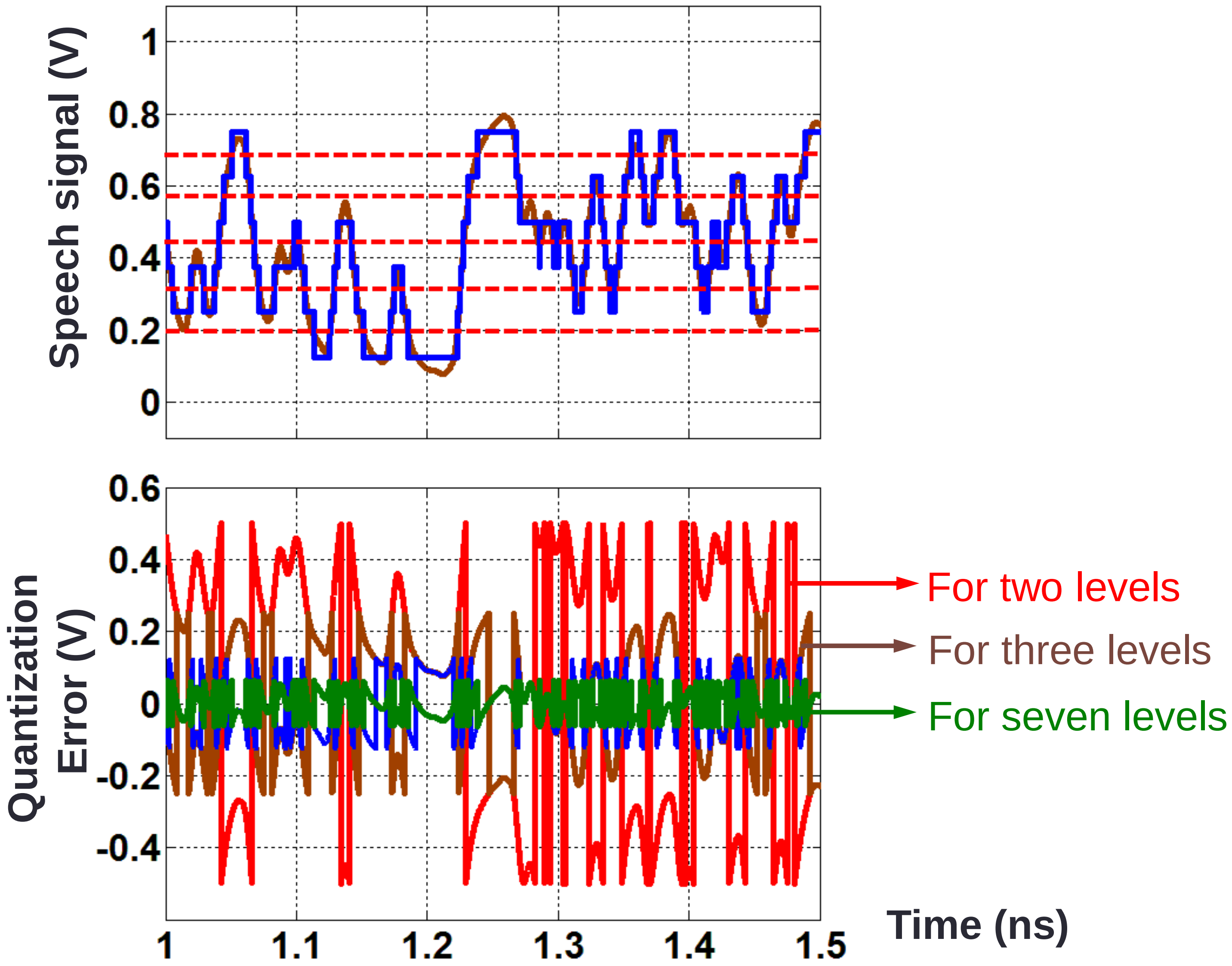


Quantization Error:
The error that happens
due to finite number
of levels available
in digital signal

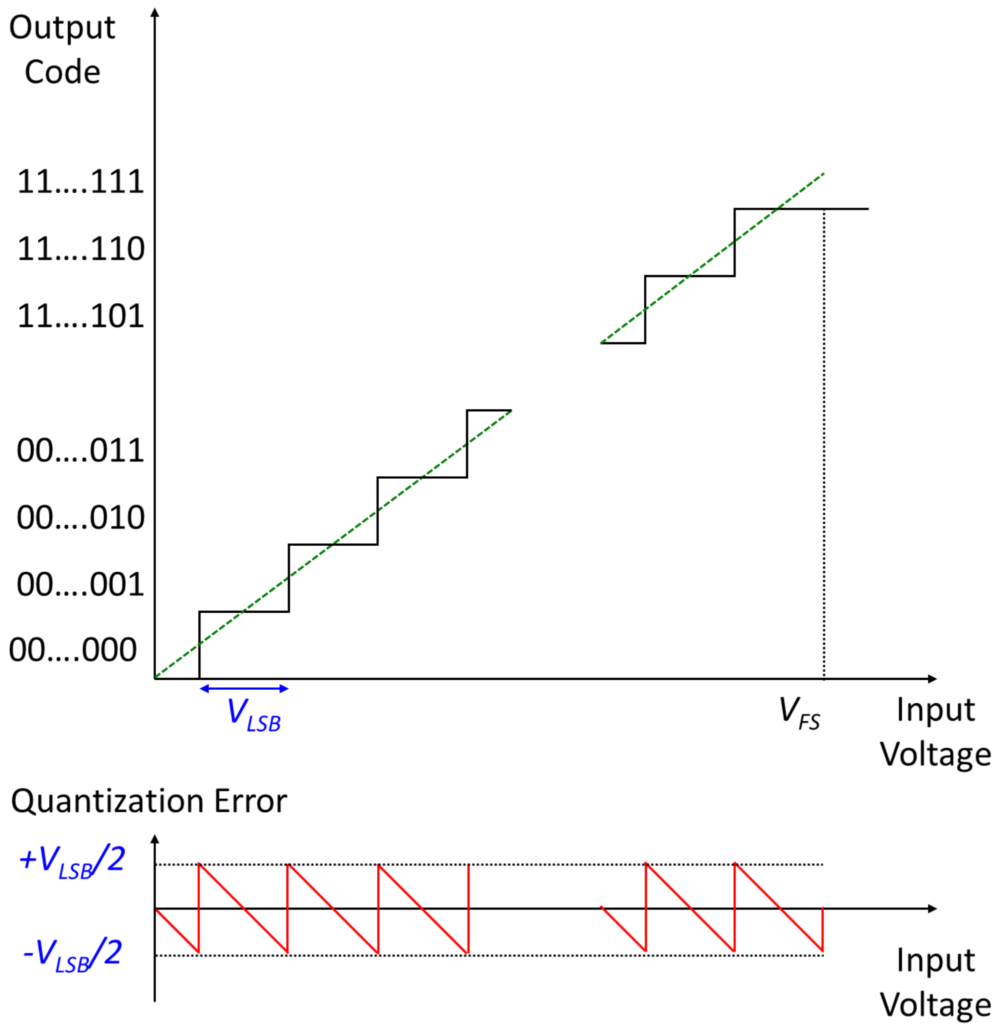
Noise is Digital system



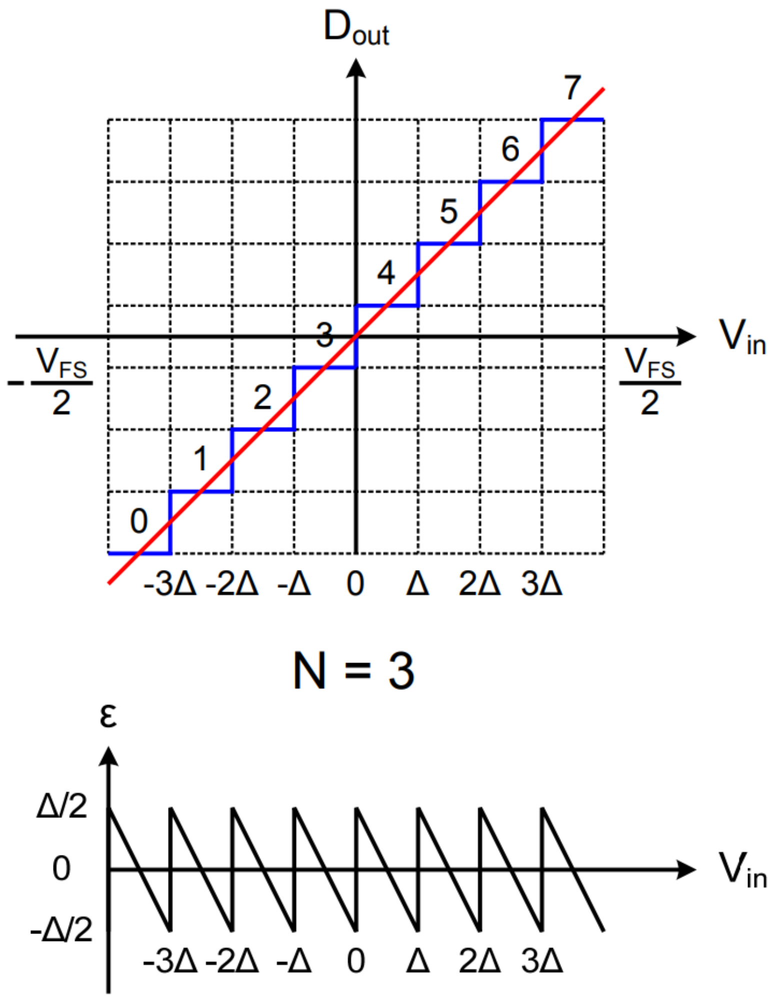
Noise is Digital system



Quantization Noise



2^N numbers of Comparisons For N bit resolution



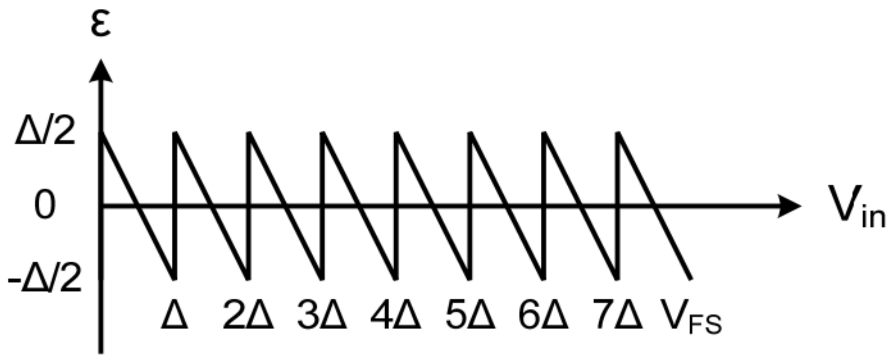
$$\Delta = \frac{V_{FS}}{2^N} = LSB$$

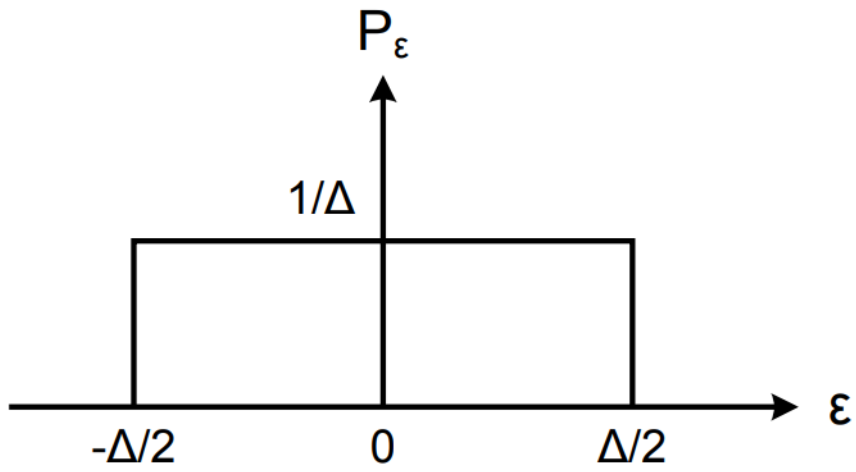
$$V_{in} \in [0, V_{FS}]$$

$$\varepsilon = D_{out}\Delta - V_{in} = D_{out}\left(\frac{V_{FS}}{2^N}\right) - V_{in}$$

$$-\frac{\Delta}{2} \le \varepsilon \le \frac{\Delta}{2}$$

“Random” quantization error is usually regarded as noise





<u>Assumptions</u>:

- N is large
- $0 \le V_{in} \le V_{FS}$ and $V_{in} >> \Delta$
- V_{in} is active
- ε is Uniformly distributed
- Spectrum of ε is white

$$\boxed{\sigma_\varepsilon^{\;2} = \int_{-\Delta/2}^{\Delta/2} \varepsilon^2 \cdot \frac{1}{\Delta} \cdot d\varepsilon = \frac{\Delta^2}{12}}$$

SQNR and ENOB

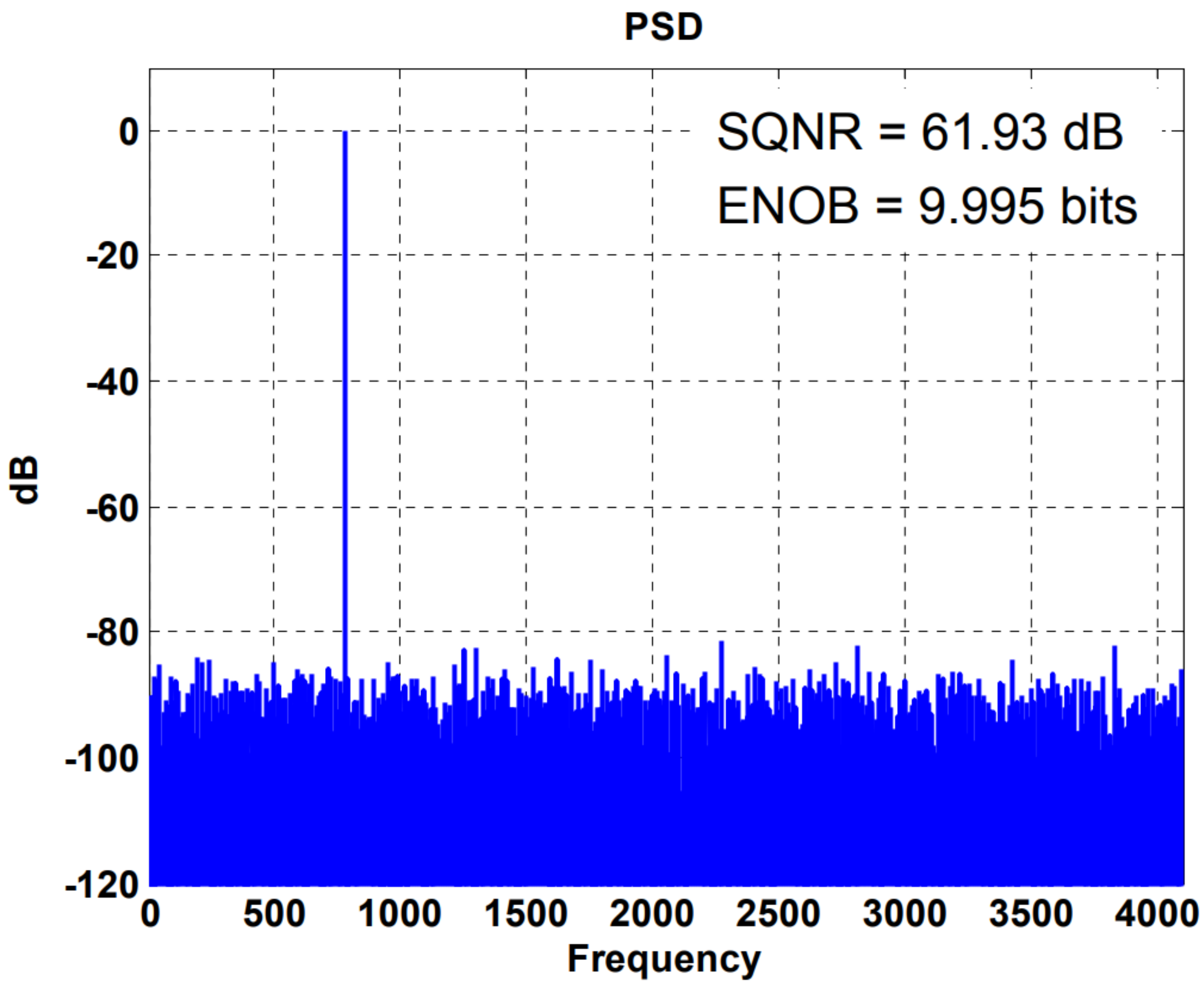
Assume V_{in} is sinusoidal with $V_{p\text{-}p} = V_{FS}$,

$$SQNR = \frac{V_{FS}^2/8}{\sigma_\varepsilon^2} = \frac{\left(2^N\Delta\right)^2/8}{\frac{\Delta^2}{12}} = 1.5\times 2^{2N},$$

$$\boxed{SQNR = 6.02\times N + 1.76\ \text{dB}}$$

N (bits)	SQNR (dB)
8	49.9
10	62.0
12	74.0
14	86.0

- SQNR depicts the theoretical performance of an ideal ADC
- In reality, ADC performance is limited by many other factors:
  - Electronic noise (thermal, 1/f, coupling/substrate, etc.)
  - Distortion (measured by THD, SFDR, IM3, etc.)



- N = 10 bits
- 8192 samples, only $f = [0, f_s/2]$ shown
- Normalized to V_{in}
- $f_s = 8192$, $f_{in} = 779$
- f_{in} and f_s must be incommensurate

$$\boxed{ENOB = \frac{SQNR - 1.76\ dB}{6.02\ dB}}$$

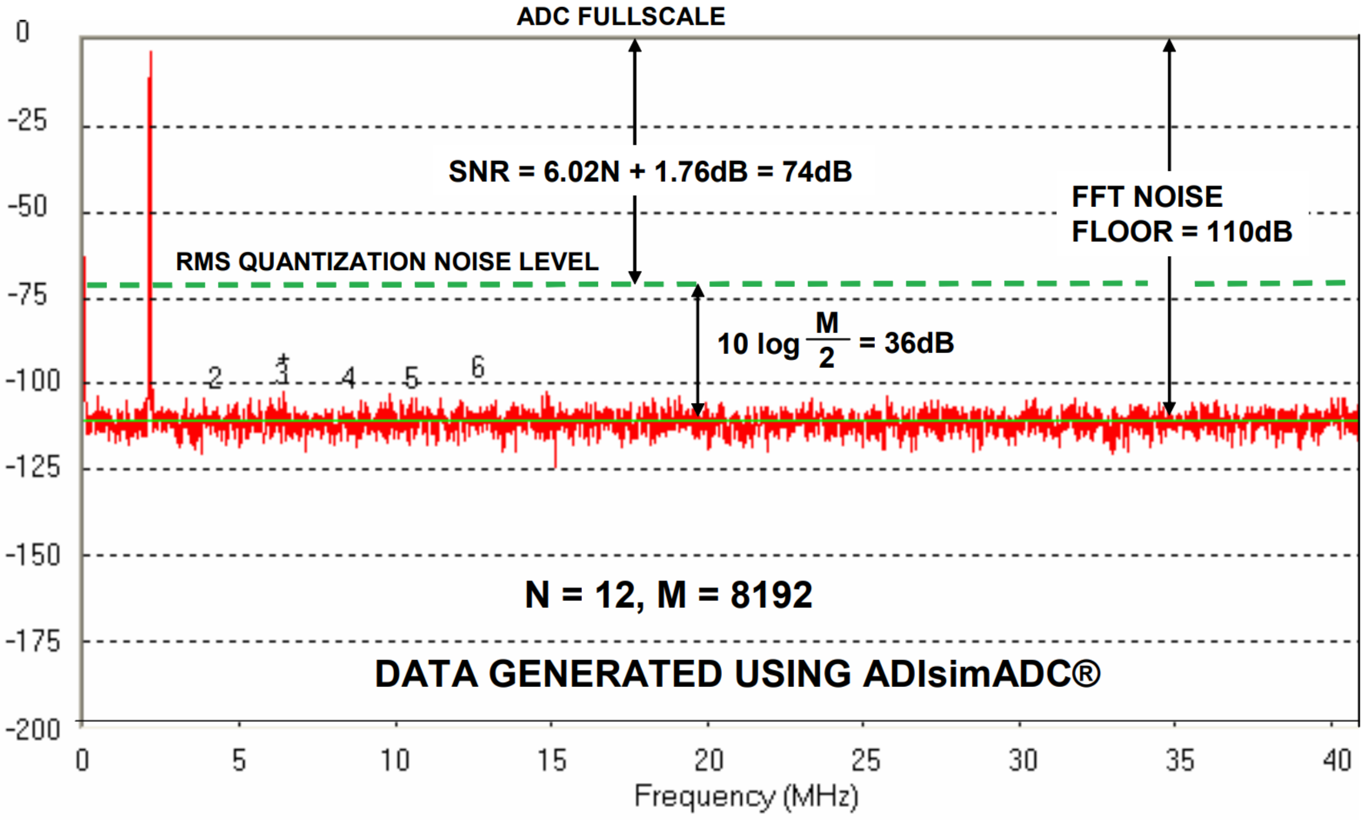


Figure 2: FFT Output for an Ideal 12-Bit ADC, Input = 2.111MHz,
f_s = 82MSPS, Average of 5 FFTs, M = 8192,
Data Generated from [ADIsimADC®]

Nonlinear Distortion

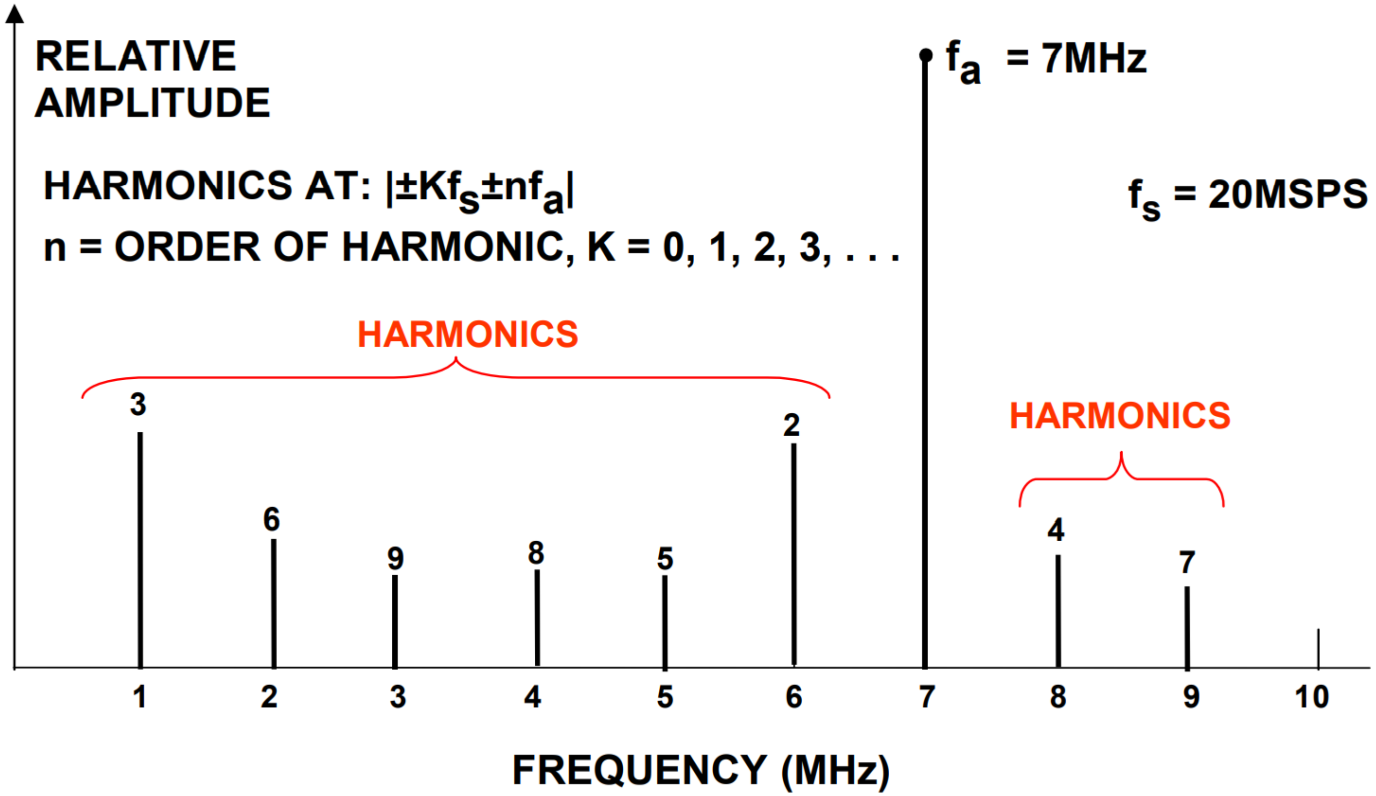


Figure 3: Location of Distortion Products: Input Signal = 7 MHz, Sampling Rate = 20 MSPS

SFDR

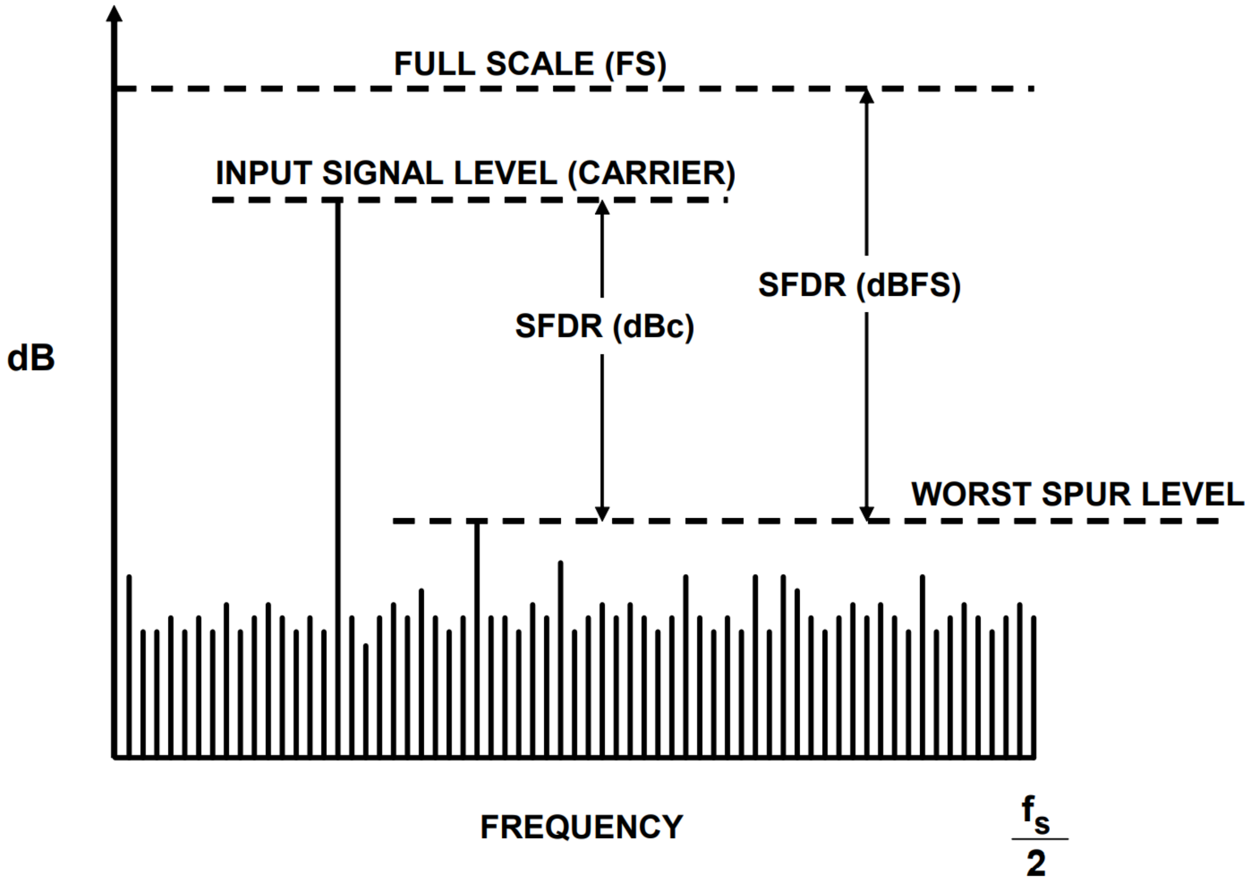


Figure 4: Spurious Free Dynamic Range (SFDR)

Useful expressions

$$\mathrm{ENOB} = \frac{\mathrm{SINAD} - 1.76\ \mathrm{dB}}{6.02}$$

$$\mathrm{ENOB} = \frac{\mathrm{SINAD}_{\mathrm{MEASURED}} - 1.76\ \mathrm{db} + 20\log\left(\dfrac{\text{Fullscale Amplitude}}{\text{Input Amplitude}}\right)}{6.02}.$$

$$\mathrm{SNR} = 20\log\left(\frac{S}{N}\right),$$

$$\mathrm{THD} = 20\log\left(\frac{S}{D}\right),$$

$$\mathrm{SINAD} = 20\log\left(\frac{S}{N+D}\right).$$

Useful expressions

$$\frac{N+D}{S} = 10^{-SINAD/20}$$

Because the denominators of Eq. 6, Eq. 7, and Eq. 8 are all equal to S, the root su
N/S and D/S is equal to (N+D)/S as follows:

$$\frac{N+D}{S} = \left[\left(\frac{N}{S}\right)^2 + \left(\frac{D}{S}\right)^2\right]^{\frac{1}{2}} = \left[\left(10^{-SNR/20}\right)^2 + \left(10^{-THD/20}\right)^2\right]$$

$$\frac{N+D}{S} = \left[10^{-SNR/10} + 10^{-THD/10}\right]^{\frac{1}{2}}.$$

Therefore, S/(N+D) must equal:

$$\frac{S}{N+D} = \left[10^{-SNR/10} + 10^{-THD/10}\right]^{-\frac{1}{2}},$$

and hence,

$$SINAD = 20\log\left(\frac{S}{N+D}\right) = -10\log\left[10^{-SNR/10} + 10^{-THD/10}\right.$$

Eq. 12 gives us SINAD as a function of SNR and THD.

Similarly, if we know SINAD and THD, we can solve for SNR as follows:

$$SNR = 20\log\left(\frac{S}{N}\right) = -10\log\left[10^{-SINAD/10} - 10^{-THD/10}\right].$$

Similarly, if we know SINAD and SNR, we can solve for THD as follows:

$$THD = 20\log\left(\frac{S}{D}\right) = -10\log\left[10^{-SINAD/10} - 10^{-SNR/10}\right].$$