Mixed-Signal IC Test & Measurement

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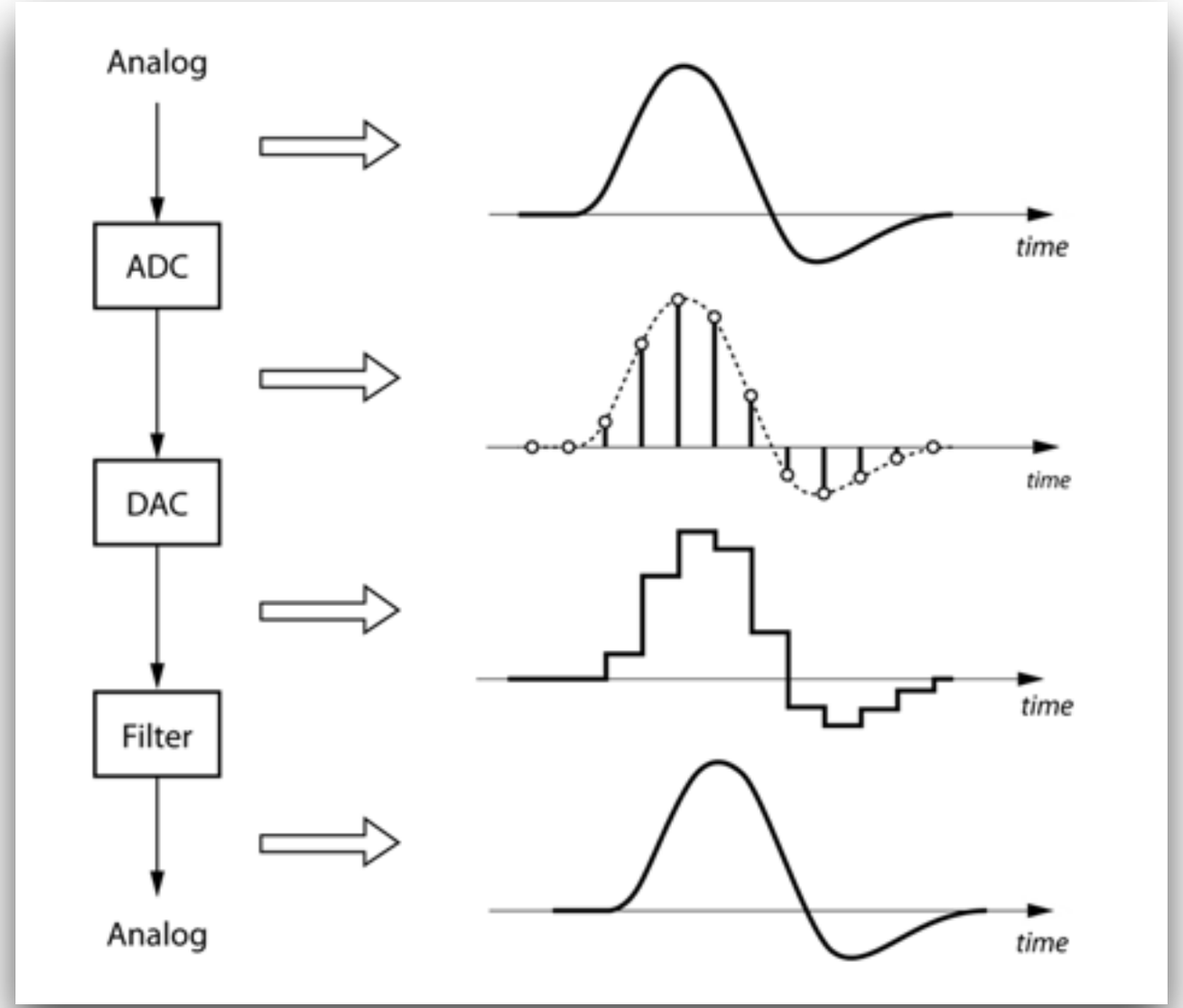
Agenda

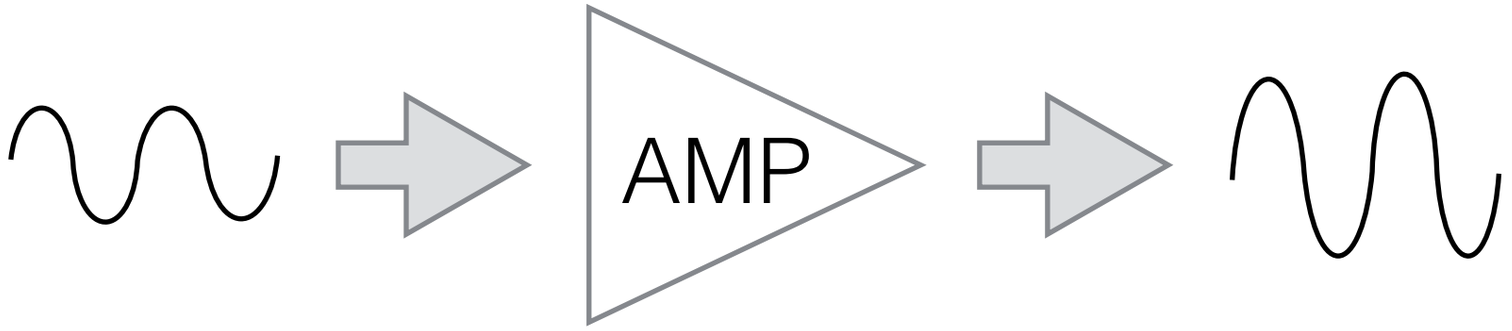
- 混合信号概述
- SAR ADC原理
- 术语及参数解析



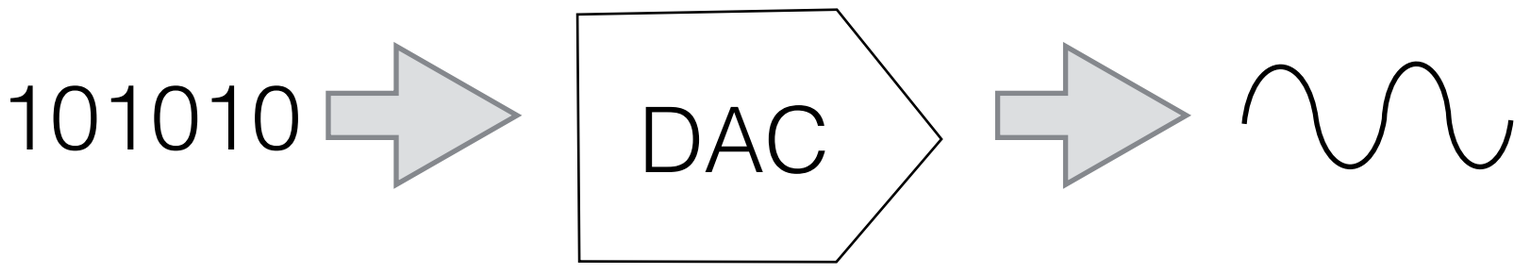
Analog or Digital

数字测试

模拟测试

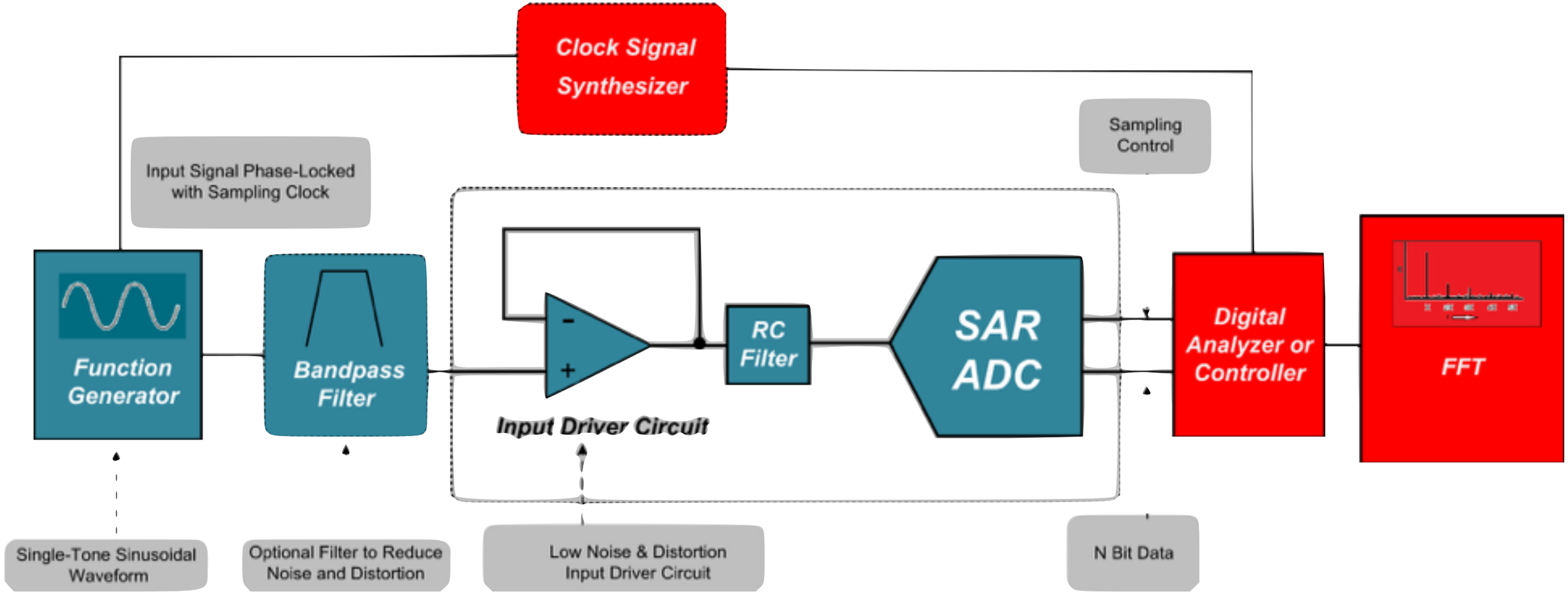


混合信号测试

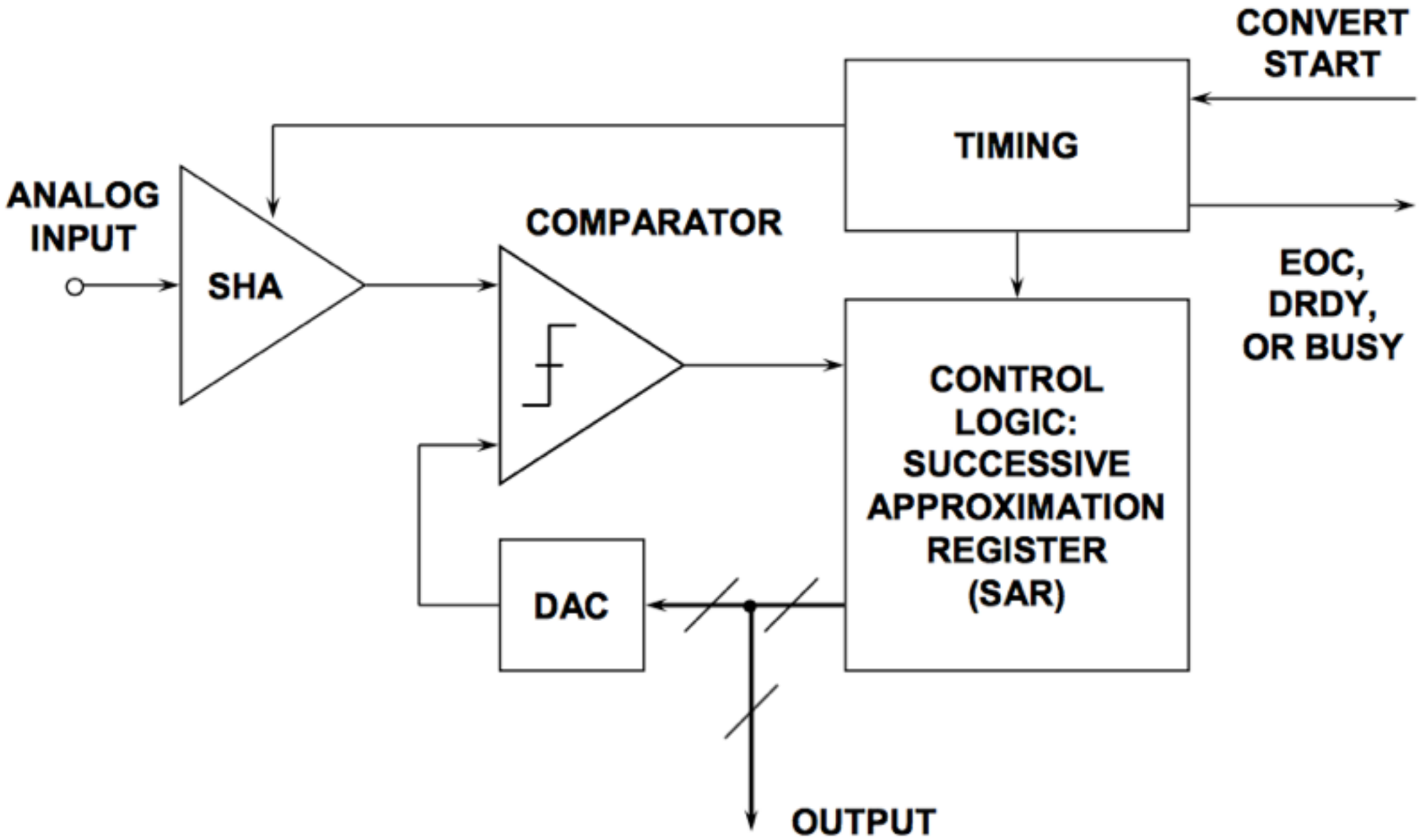


Analog to Digital

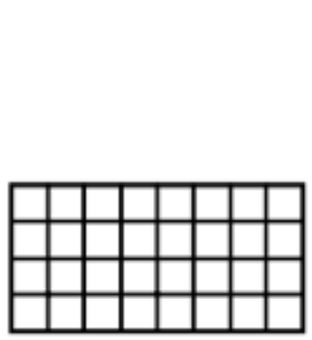
混合信号测试测量中，最经典的莫过于ADC测试

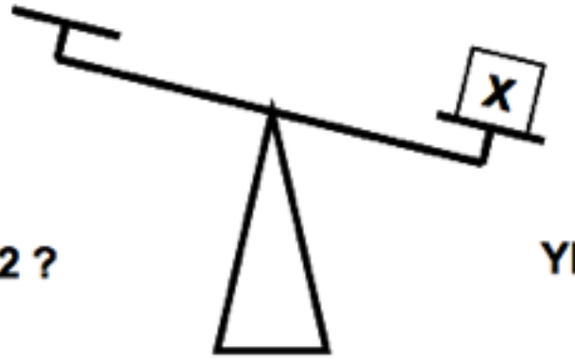


SAR ADC


CONVERT
START
TIMING
ANALOG
INPUT
SHA
COMPARATOR
EOC,
DRDY,
OR BUSY
CONTROL
LOGIC:
SUCCESSIVE
APPROXIMATION
REGISTER
(SAR)
DAC
OUTPUT

SAR ADC



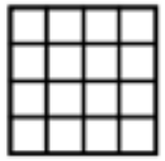


TEST

ASSUME X = 45

IS X ≥ 32 ?

YES → RETAIN 32 → 1



IS X ≥ (32 +16) ?

NO → REJECT 16 → 0

IS X ≥ (32 +8) ?

YES → RETAIN 8 → 1

IS X ≥ (32 +8 + 4) ?

YES → RETAIN 4 → 1

IS X ≥ (32 +8 + 4 + 2) ?

NO → REJECT 2 → 0

IS X ≥ (32 +8 + 4 + 2 + 1) ?

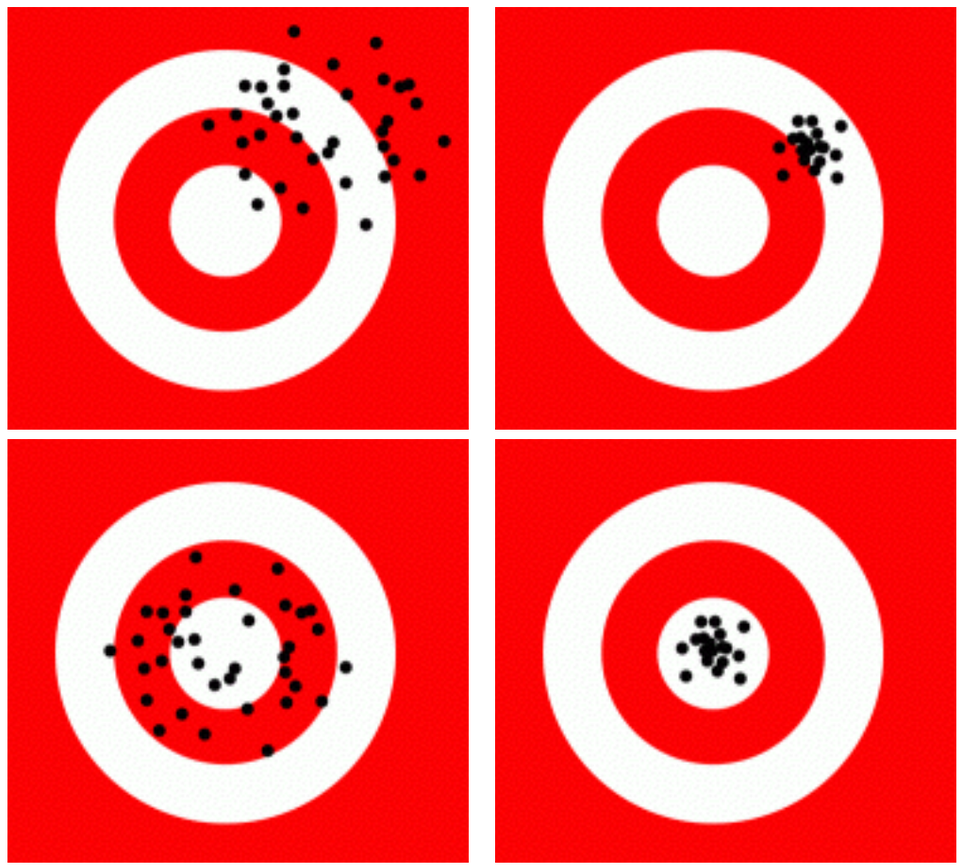
YES → RETAIN 1 → 1

TOTALS: $X = 32 + 8 + 4 + 1 = 45_{10} = 101101_2$

Definitions

- 静态参数 **DC**
  - **Resolution／INL／DNL** **ADC／DAC Both**
  - **OE／GE／TUE**
    - Other：VAIN／IILA／CAIN／VREF／IILR／CREF／VIH／VIL／VHYST／IIL／CIN／VOH／VOL／IOL／COUT／AVDD／DVDD／IPD
- 动态参数 **AC**
  - **SINAD／SNR／THD／SFDR／IMD**
    - Other：Conversion Time／Throughput／Acquisition Time／Serial-Clock Frequency

Precision & Correctness &Accuracy & Resolution



Precision 精密度

精密度高，不一定正确度高

Correctness 正确度

正确度高，不一定精密度高

Accuracy 精确度

是精密度与正确度的总额和体现

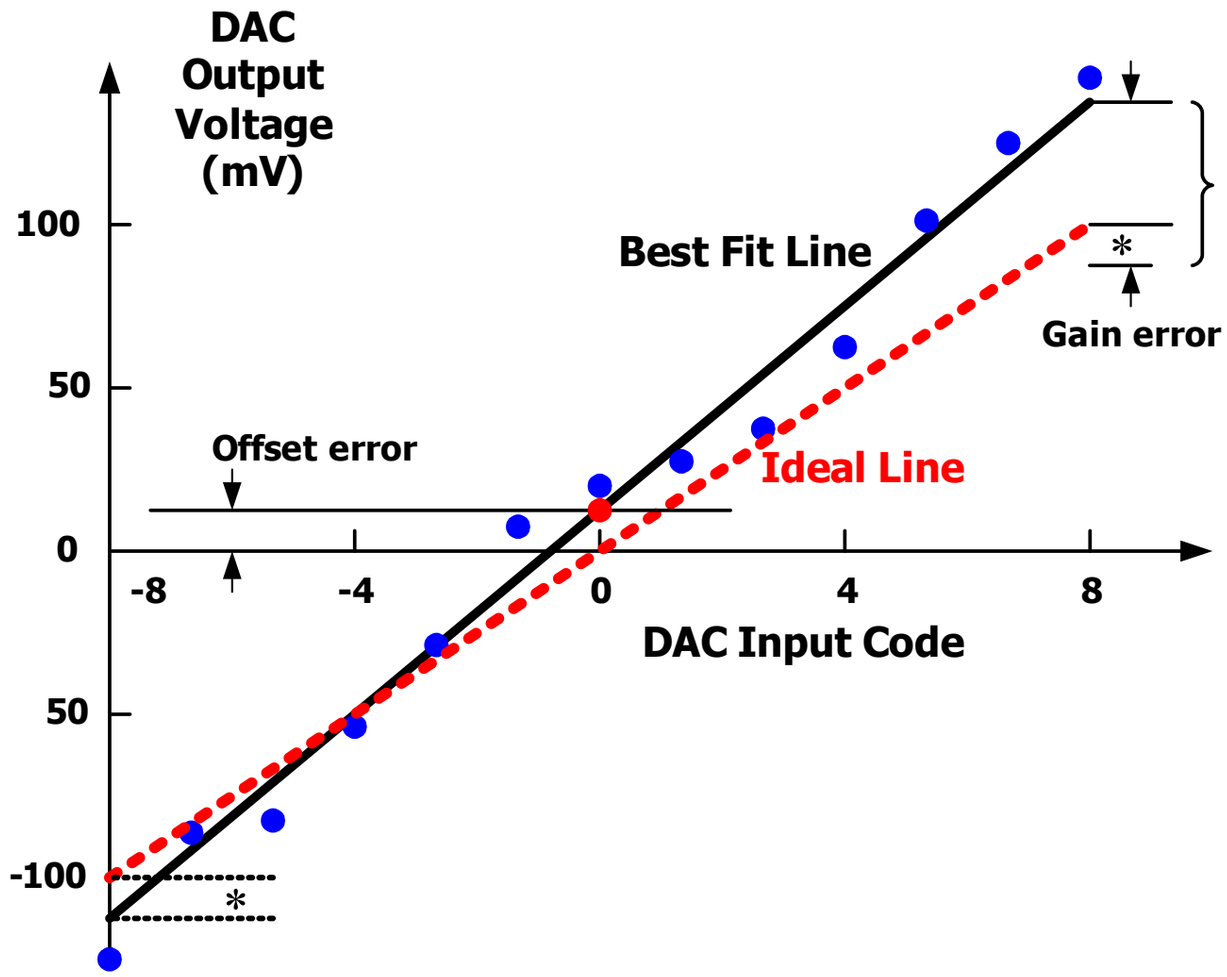
Resolution 分辨率

对于满量程的一个比率，相对值

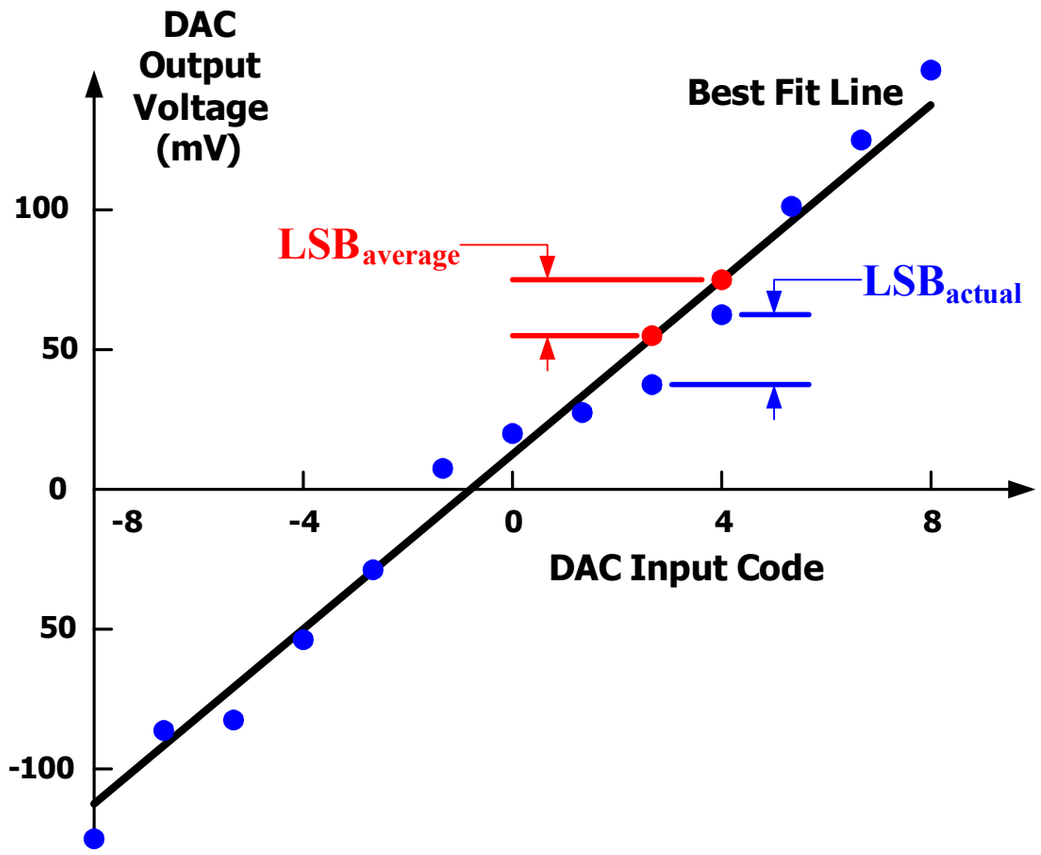
OE & GE

这是DA／AD都有的参数

- **Offset Error**定义为器件理想输出与实际输出之差。通常通过测量第一个数字代码转换或“零”转换的电压，并将它与理论零点电压相比较得到。
- **Gain Error**是理想传递函数和实际斜率的差别。增益误差通常在模数转换器最末或最后一个传输代码转换点计算。

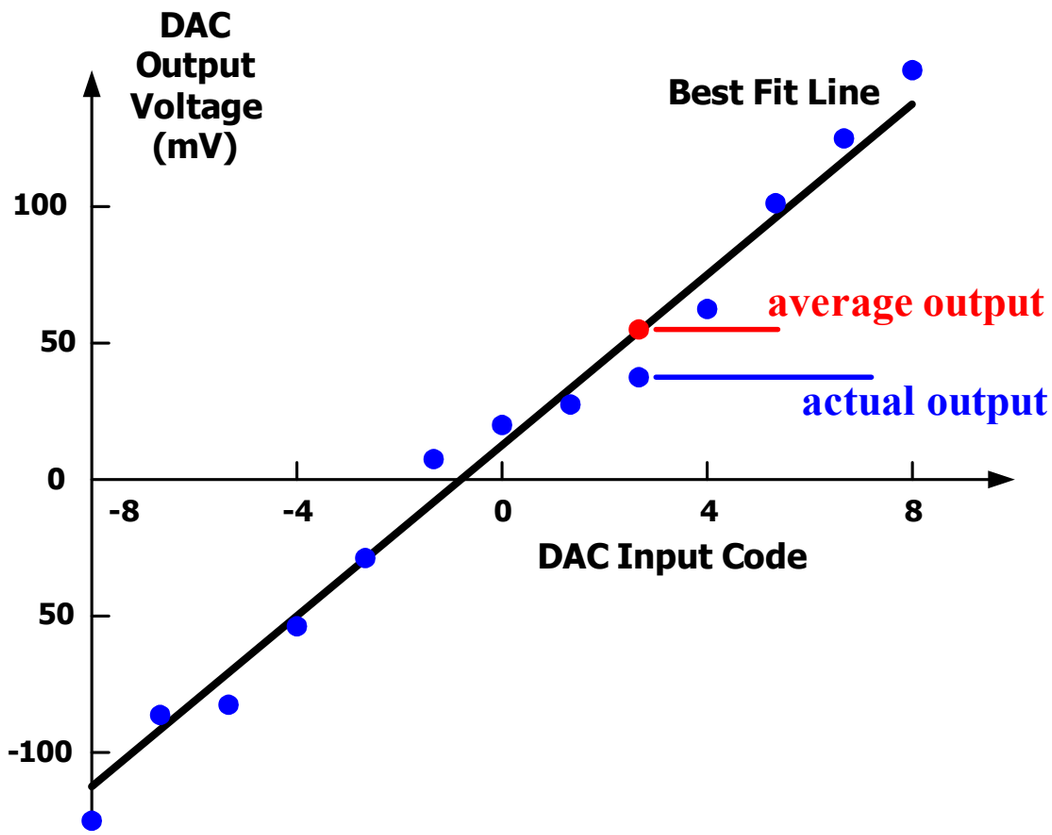


DNL & INL



DNL: $LSB_{actual} - LSB_{average}$

- **DNL**主要描述的是代码步距与理想步距之差。

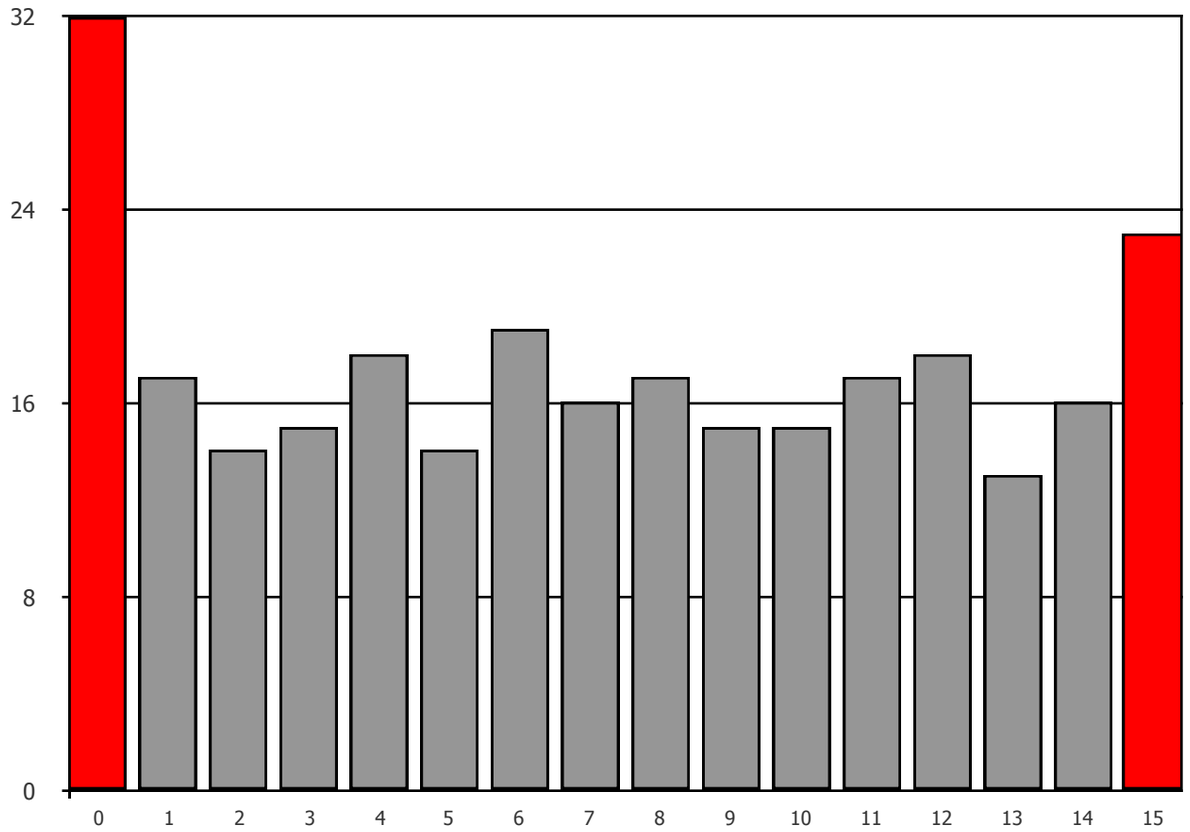


INL: average output − actual output

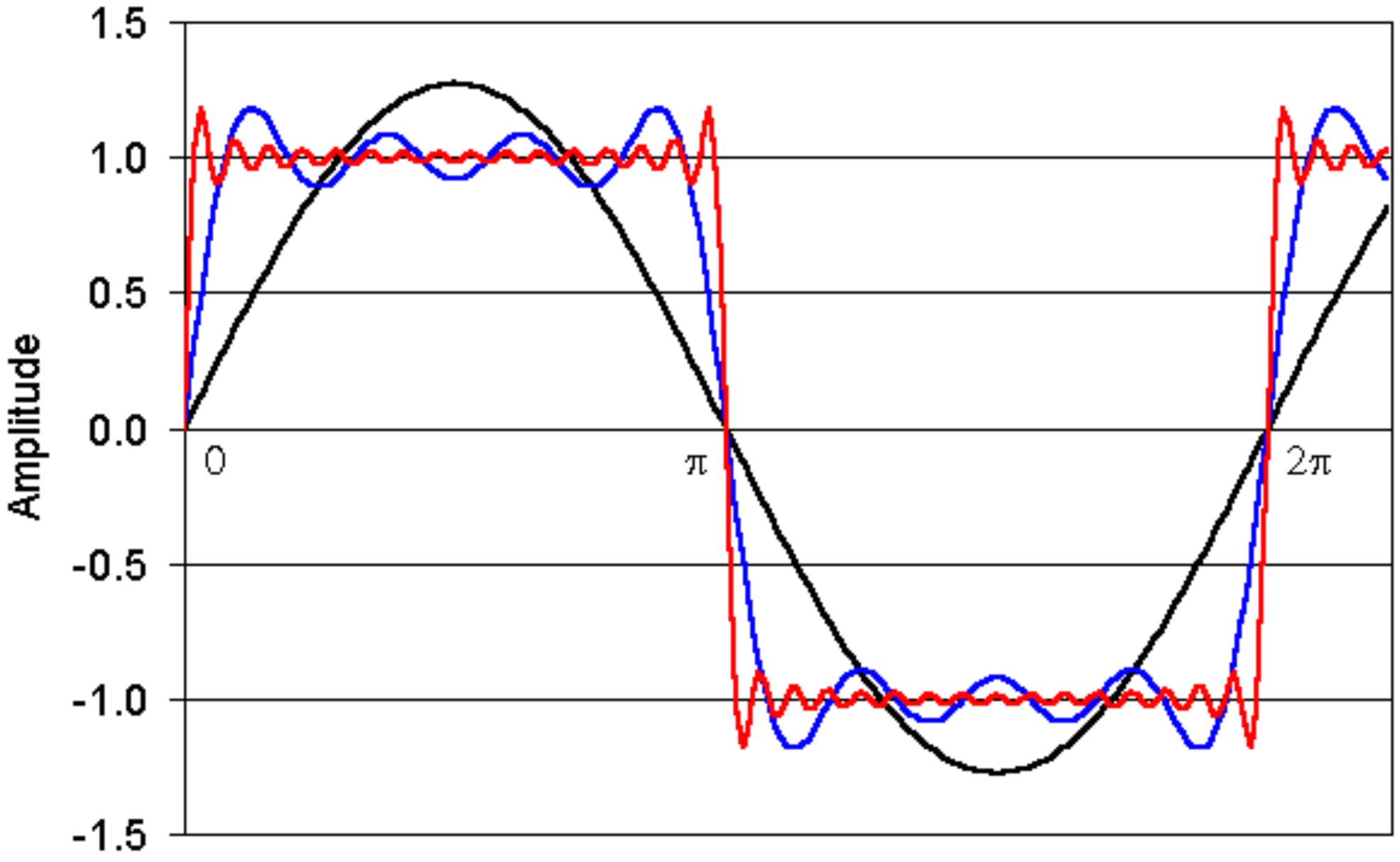
- **INL**描述的实际转换曲线与理想转换曲线的差异。

Histogram

- 纵轴为点数，横轴为**ADC**转换代码点。
- 图示为**8**位**DAC**测试**4**位**ADC**的直方图。理论上**4**位**ADC**的每个代码转换点应该对应**16**个点，由此很容易就可以得出每个点的**DNL**和**Offset**。

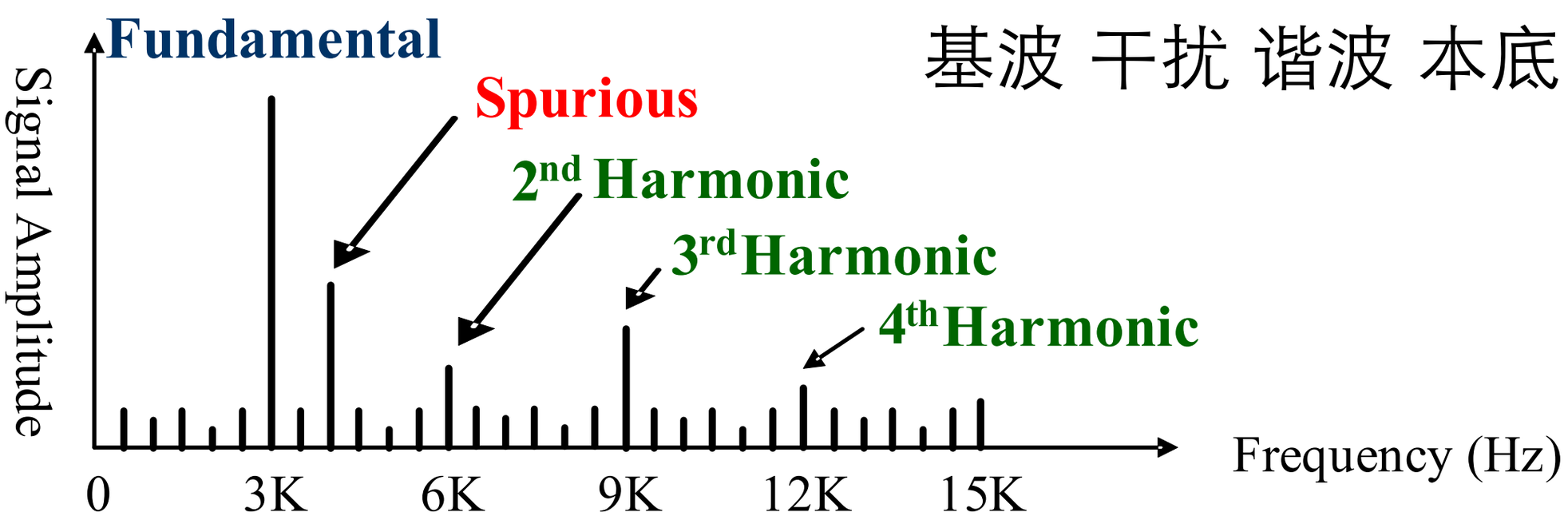


FFT



FFT

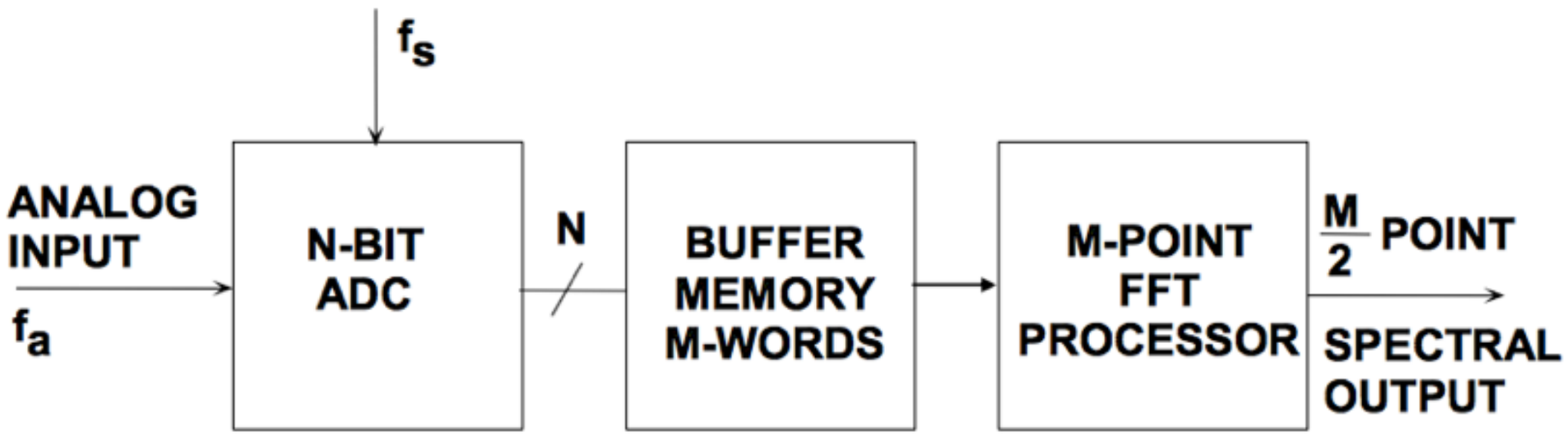
- **ADC**的动态测试基本就是一个采集和分析的频谱的过程。
- 频谱的获得需要正确的方法，遵守采样定理，及基本的采样准则。
- 应用数学工具对采集的频谱数据，对基波、谐波、噪声进行计算和分析得到最终的结果。



基波 干扰 谐波 本底

System

- 一个标准的采样时钟
- 一个完美的Sine Wave
- 一个足够空间的数字存储系统
- 一套完美的算法



SNR／SINAD／THD

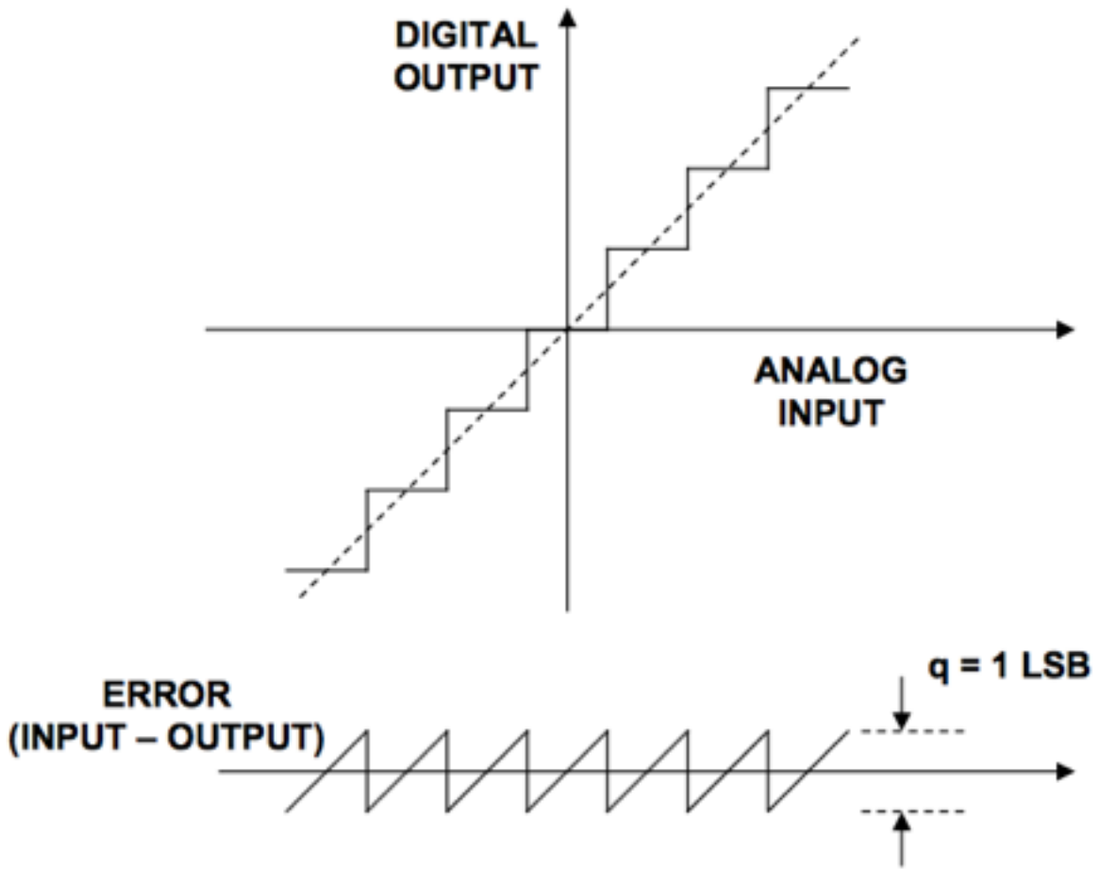
$$\mathrm{SNR} = 20\log\left(\frac{\mathrm{S}}{\mathrm{N}}\right),$$

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

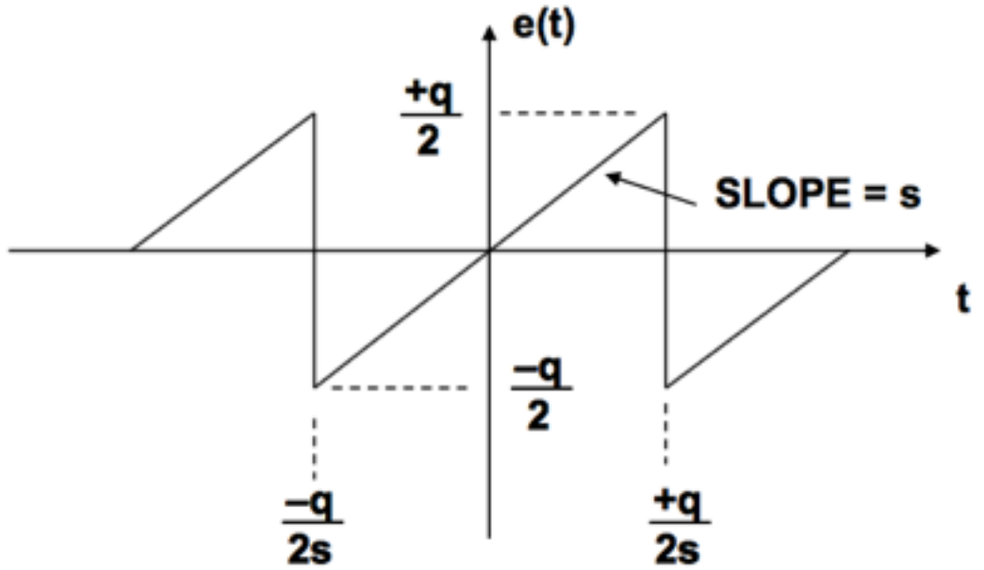
$$\mathrm{SINAD} = 20\log\left(\frac{\mathrm{S}}{\mathrm{N}+\mathrm{D}}\right).$$

- SNR（Signal-To-Noise Ratio，信噪比）
- SINAD or SNAD（Signal-To-Noise And Distortion，信号与噪声失真比）
- THD（Total Harmonic Distortion，总谐波失真或谐波失真）

Quantization Noise



理想N位ADC的量化噪声



量化误差 vs. 时间

均方根量化噪声 $= \sqrt{e^2(t)} = \frac{q}{\sqrt{12}}.$

SNR & N-Bit

满量程输入正弦波 $= v(t) = \frac{q2^N}{2}\sin(2\pi ft).$

满量程输入的均方根值 $= \frac{q2^N}{2\sqrt{2}}.$ 均方根量化噪声 $= \sqrt{e^2(t)} = \frac{q}{\sqrt{12}}.$

$$\text{SNR} = 20\log_{10}\frac{\text{rms value of FS input}}{\text{rms value of quantization noise}}$$

$$\text{SNR} = 20\log_{10}\left[\frac{q2^N/2\ \sqrt{2}}{q/\sqrt{12}}\right] = 20\log_{10}2^N + 20\log_{10}\sqrt{\frac{3}{2}}$$

$\text{SNR} = 6.02N + 1.76\text{dB},$ DC至$f_s/2$带宽范围

SINAD & ENOB

用SINAD代替理想公式中的SNR，得到ENOB

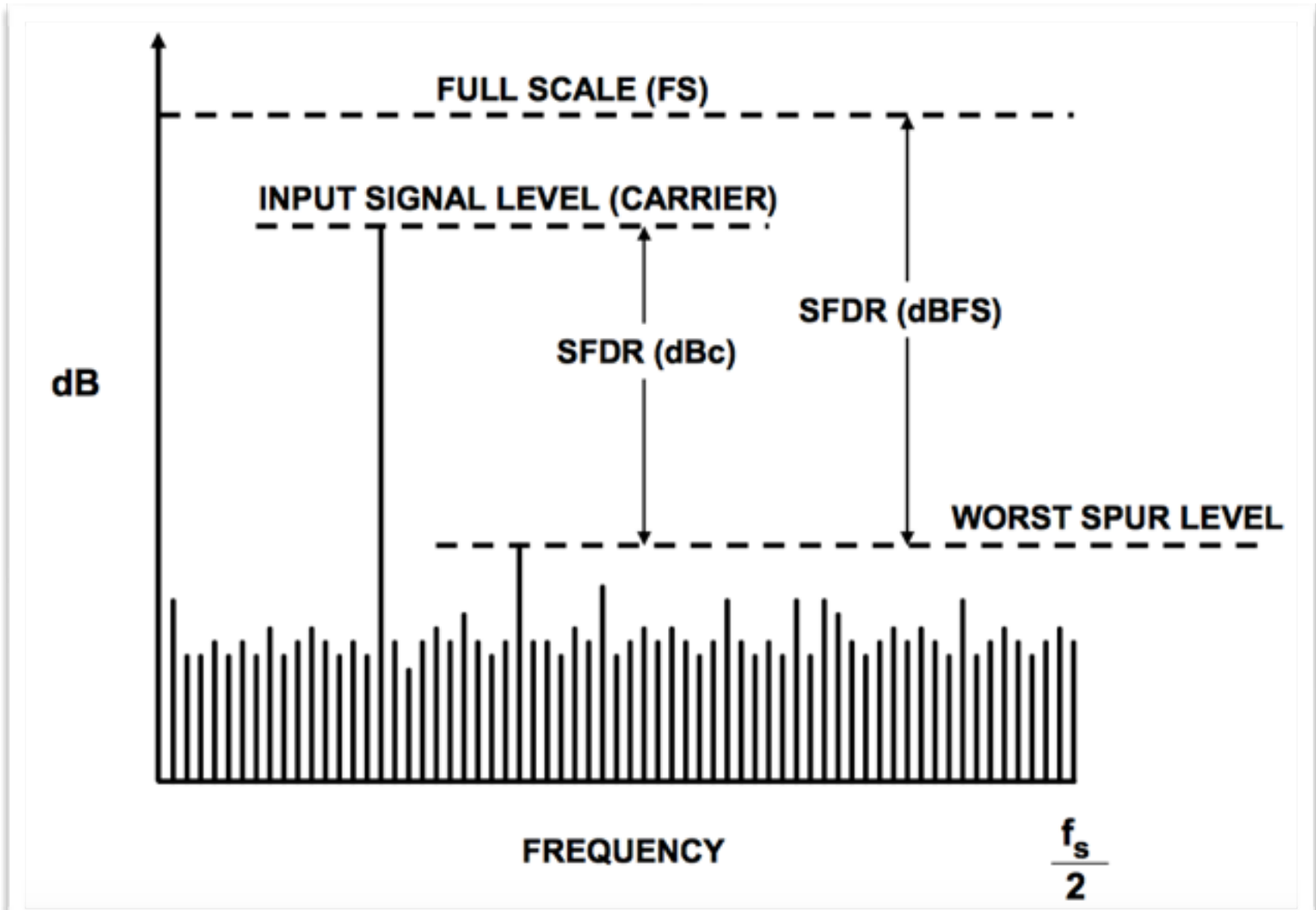
$$\mathrm{ENOB} = \frac{\mathrm{SINAD} - 1.76\ \mathrm{dB}}{6.02}\ .$$

输入信号幅度较小时，可增加修正值

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

SFDR

- 无杂散动态范围

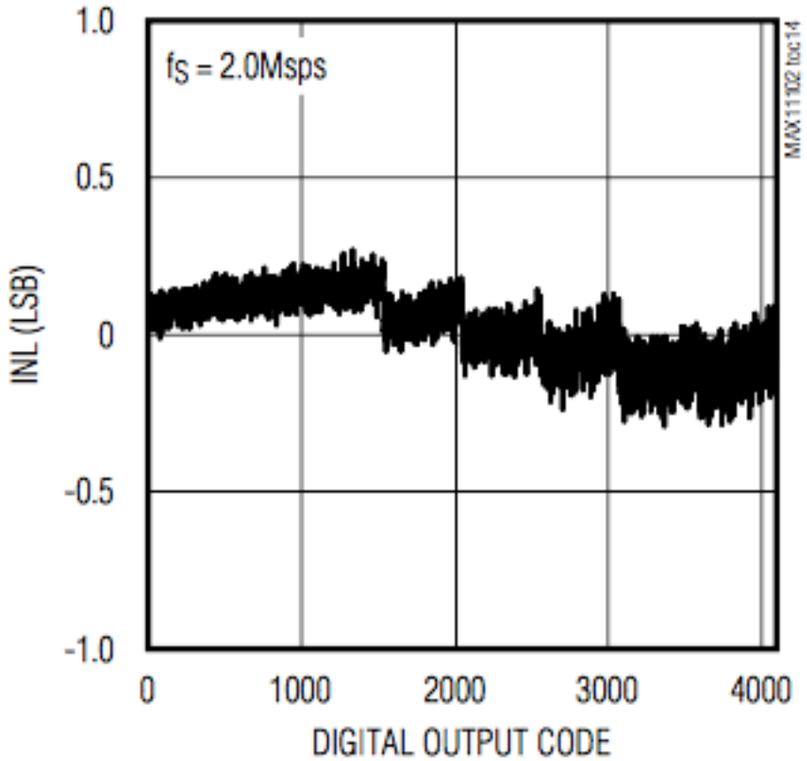


END

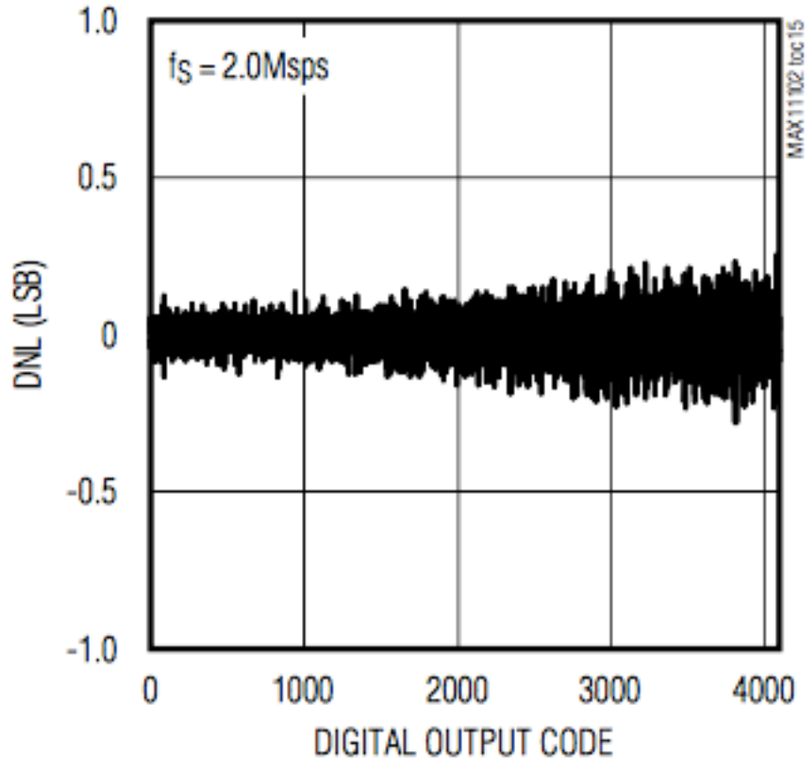
Juning
wechat：HotCube

MAX11105

INTEGRAL NONLINEARITY vs. DIGITAL OUTPUT CODE



DIFFERENTIAL NONLINEARITY vs. DIGITAL OUTPUT CODE



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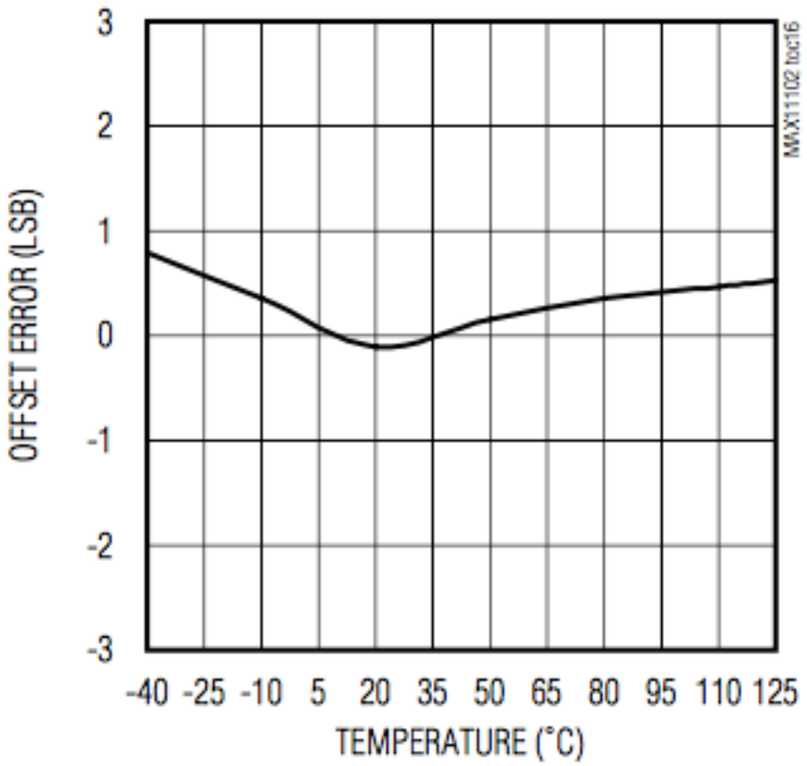
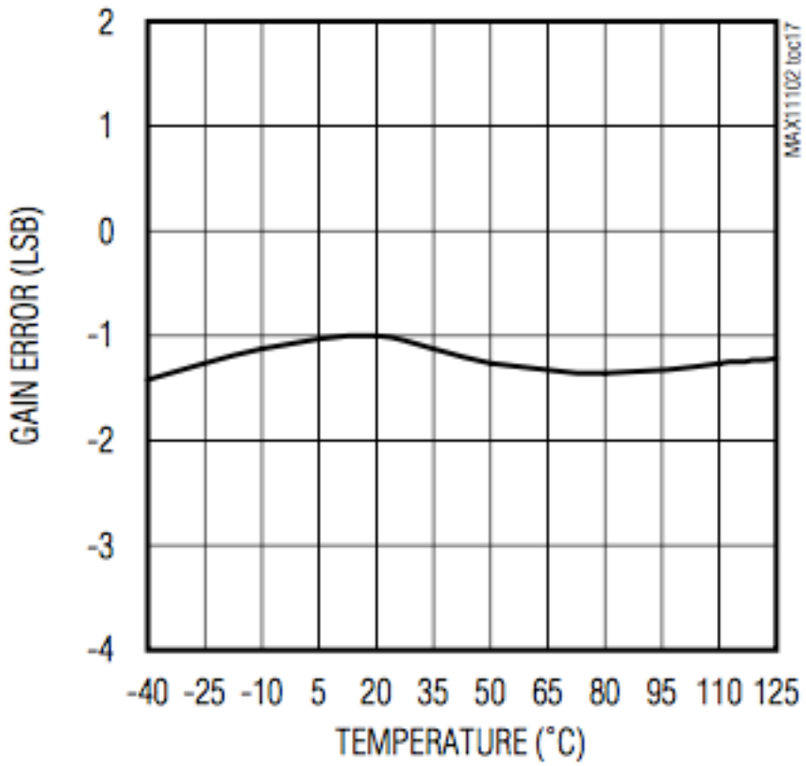
OFFSET ERROR vs. TEMPERATURE

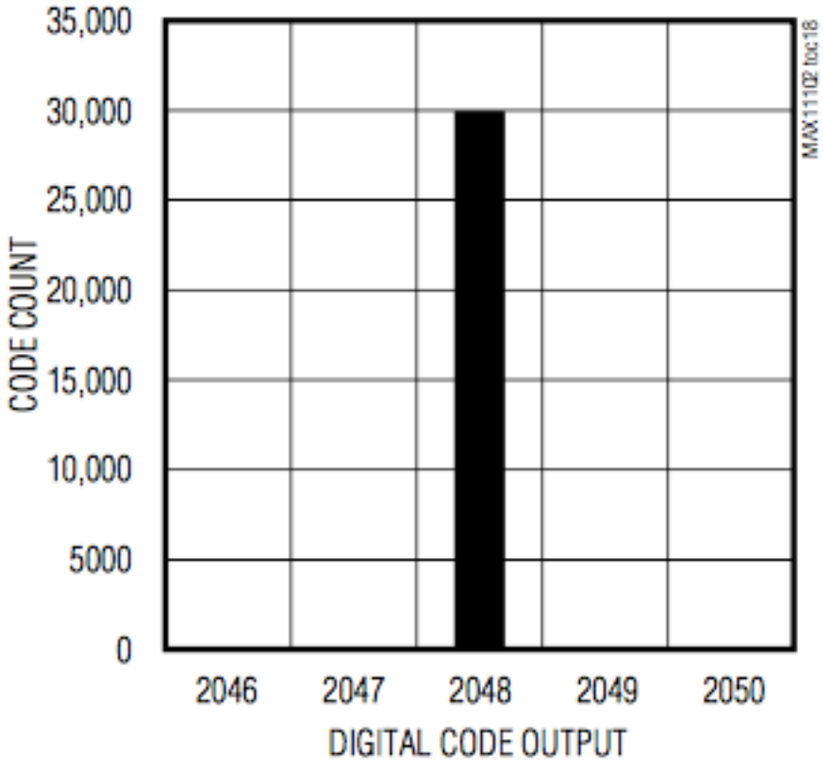


GAIN ERROR vs. TEMPERATURE

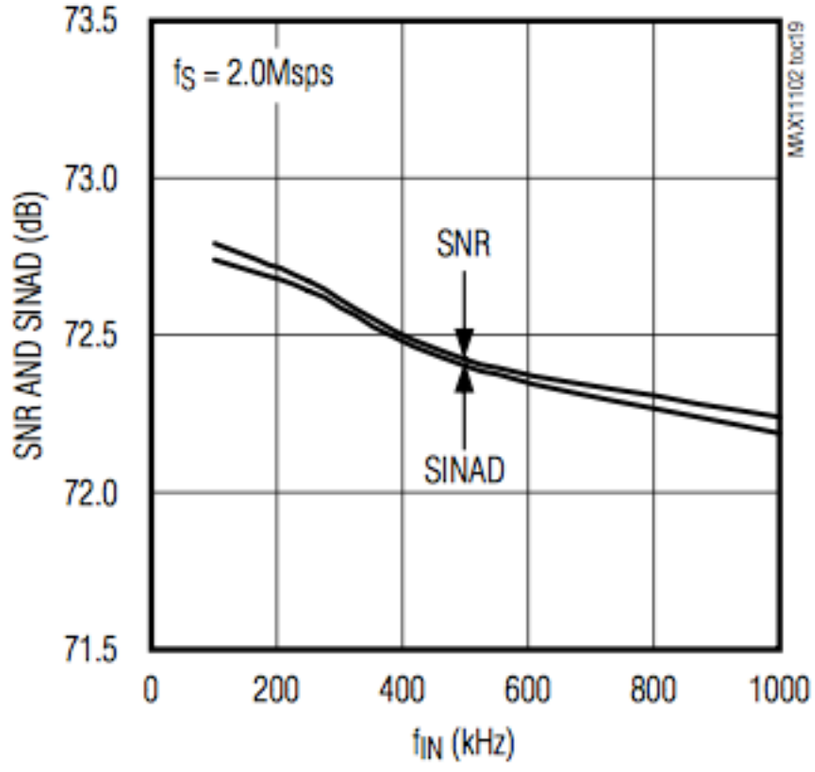


MAX11105

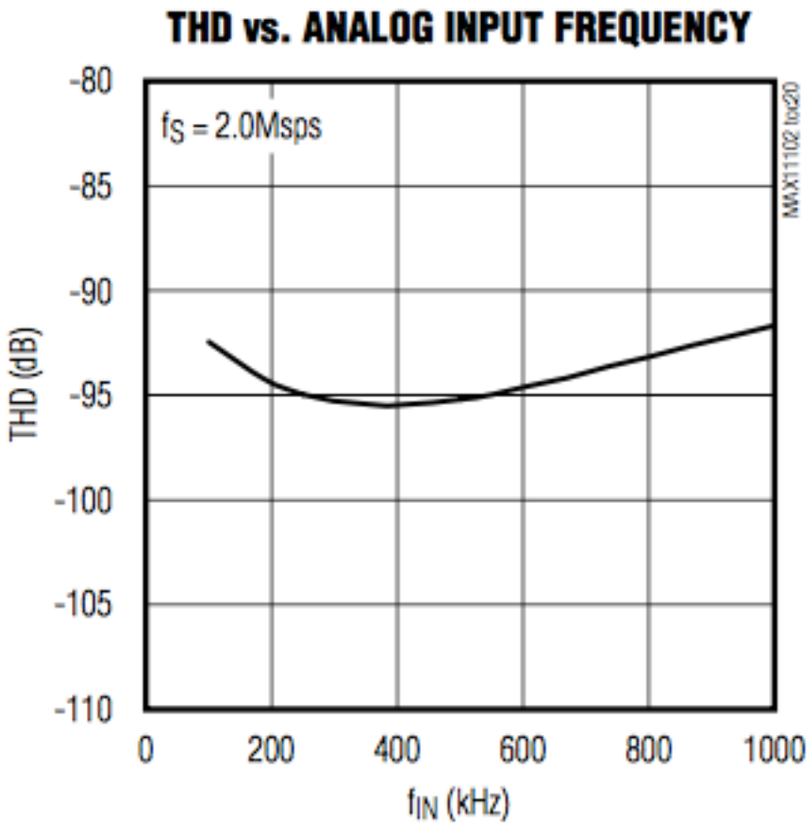
HISTOGRAM FOR 30,000 CONVERSIONS

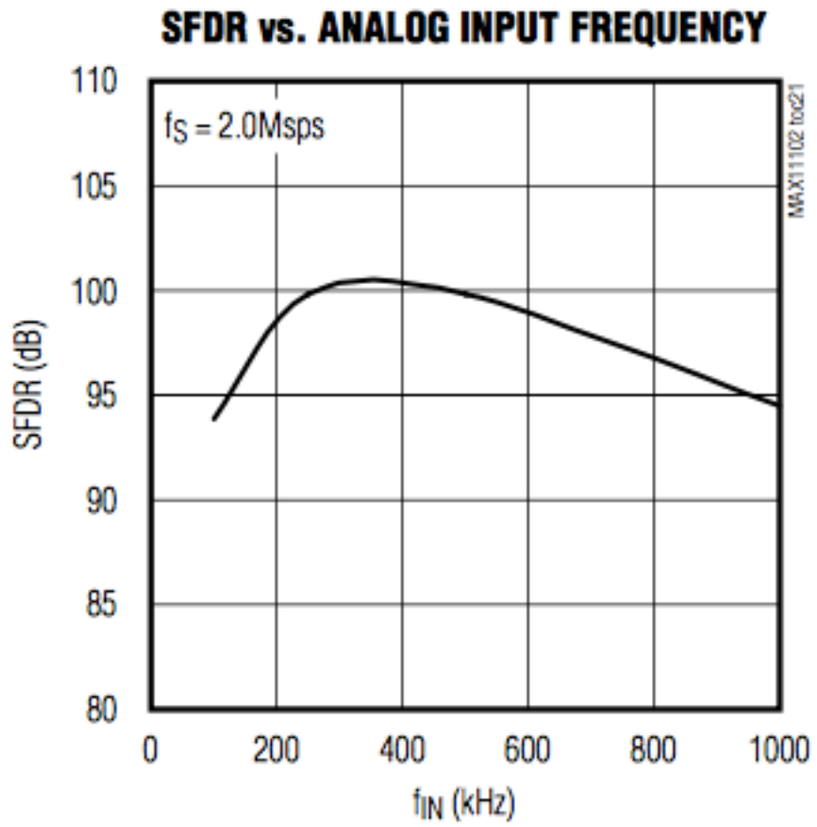


SNR AND SINAD vs. ANALOG INPUT FREQUENCY



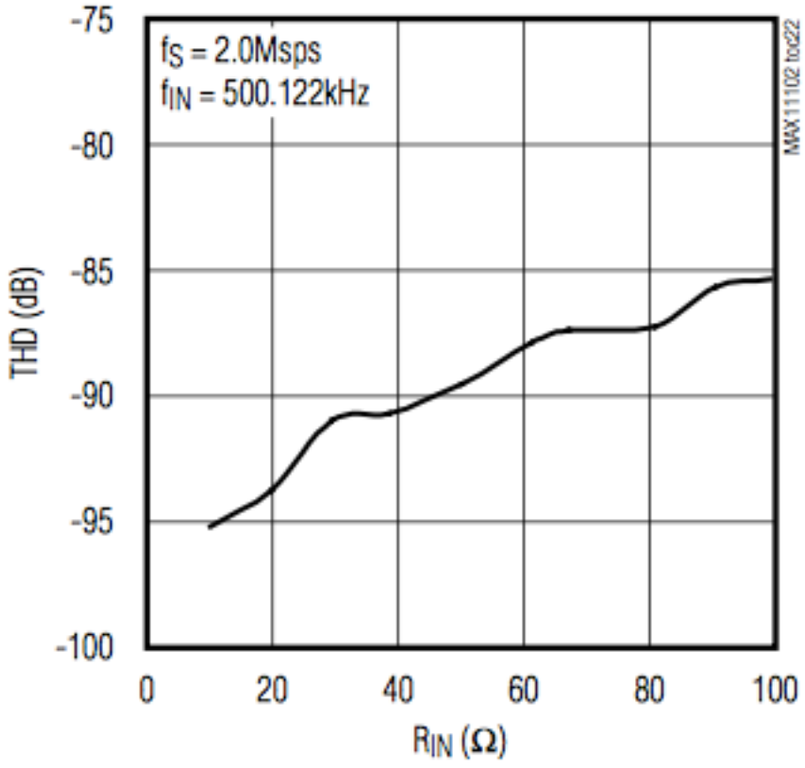
MAX11105


THD vs. ANALOG INPUT FREQUENCY
fS = 2.0Msps
MAX11102 toc20
THD (dB)
-80
-85
-90
-95
-100
-105
-110
0
200
400
600
800
1000
fIN (kHz)

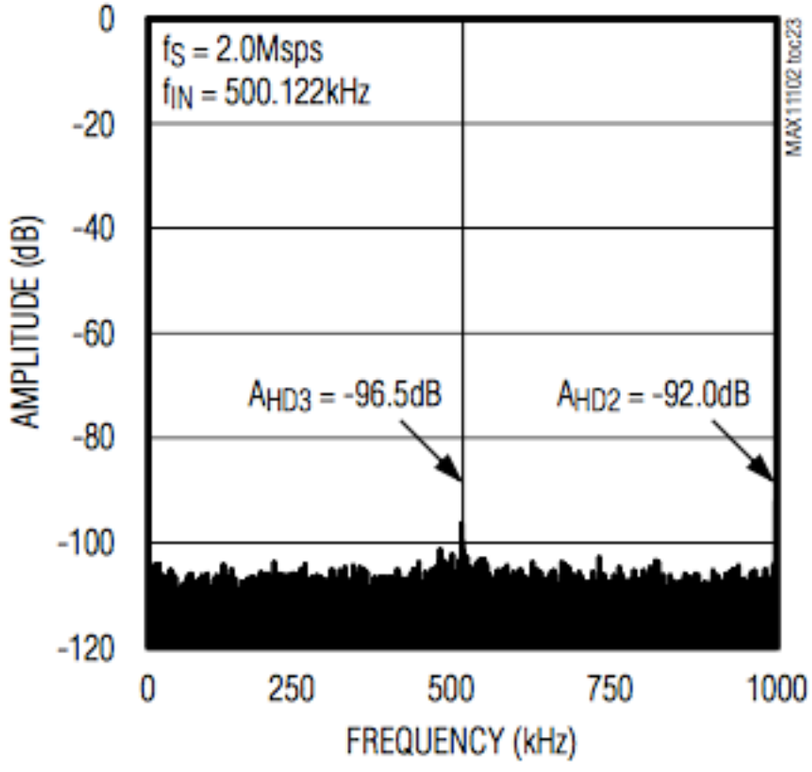

SFDR vs. ANALOG INPUT FREQUENCY
fS = 2.0Msps
MAX11102 toc21
SFDR (dB)
110
105
100
95
90
85
80
0
200
400
600
800
1000
fIN (kHz)

MAX11105

THD vs. INPUT RESISTANCE

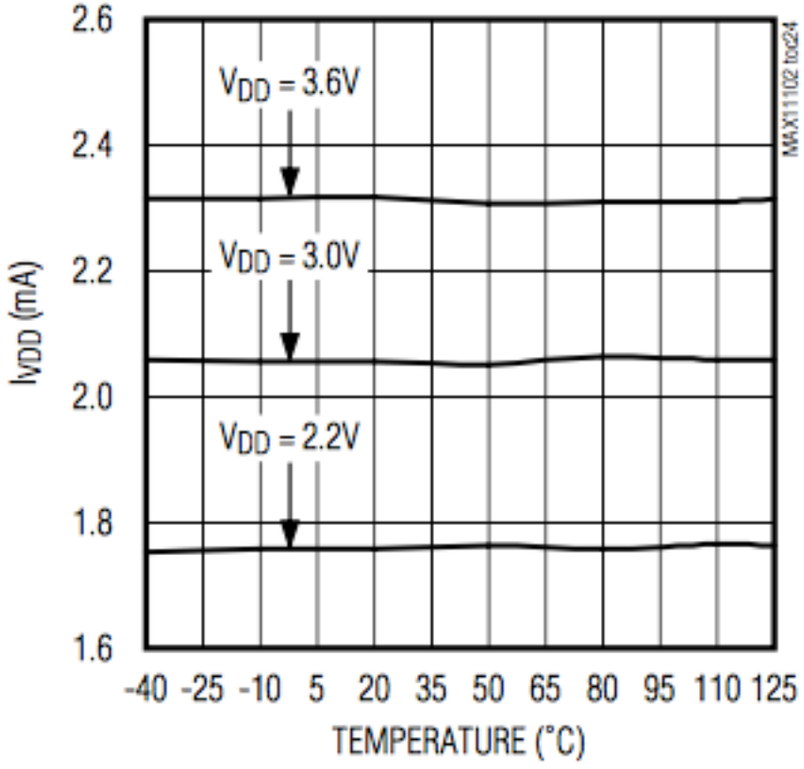


500kHz SINE-WAVE INPUT (16,834-POINT FFT PLOT)

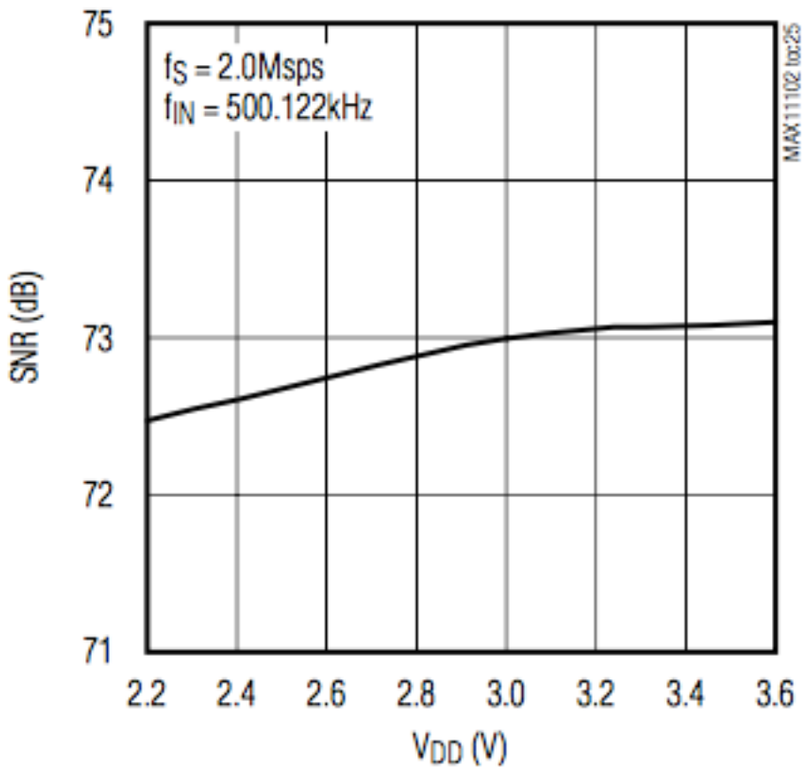


MAX11105

ANALOG SUPPLY CURRENT vs. TEMPERATURE

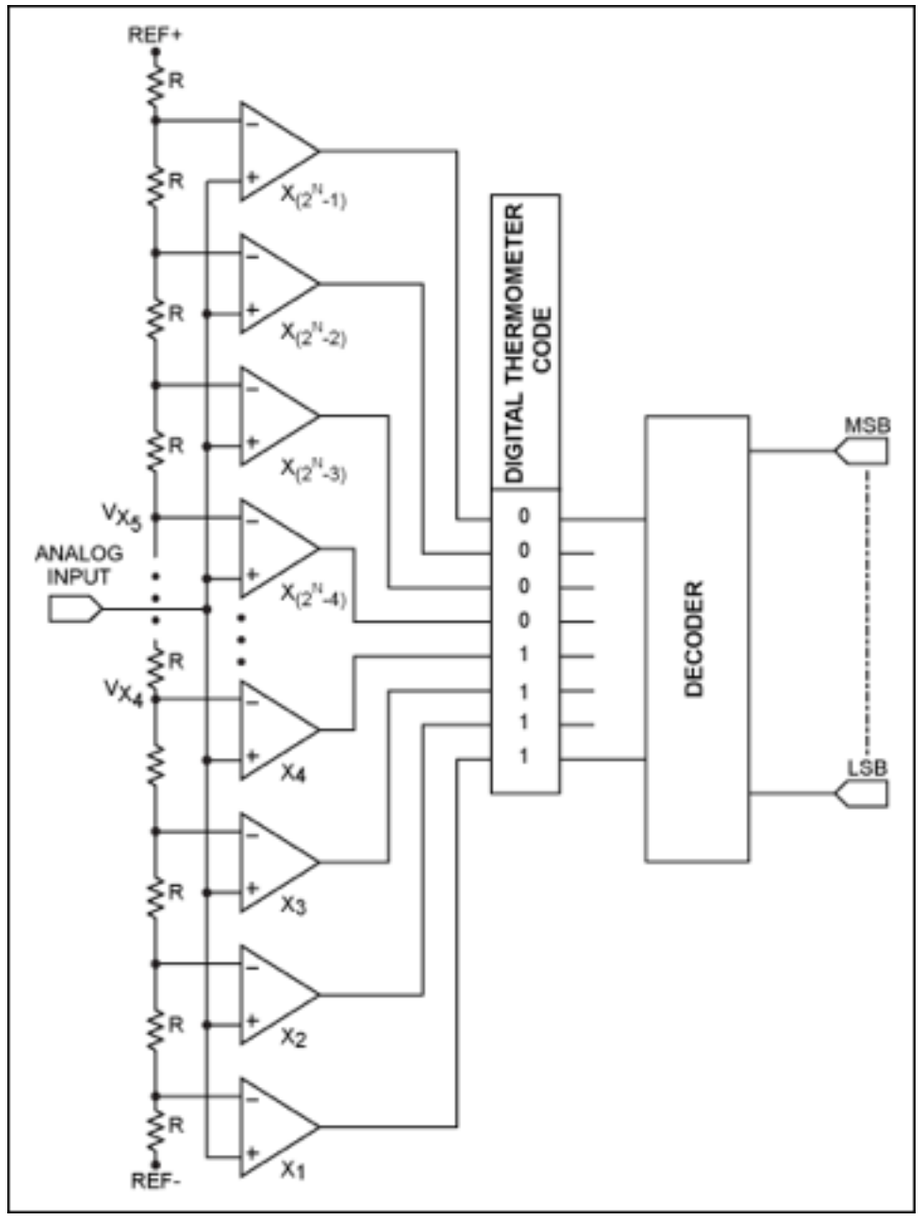


SNR vs. REFERENCE VOLTAGE (V_{DD})



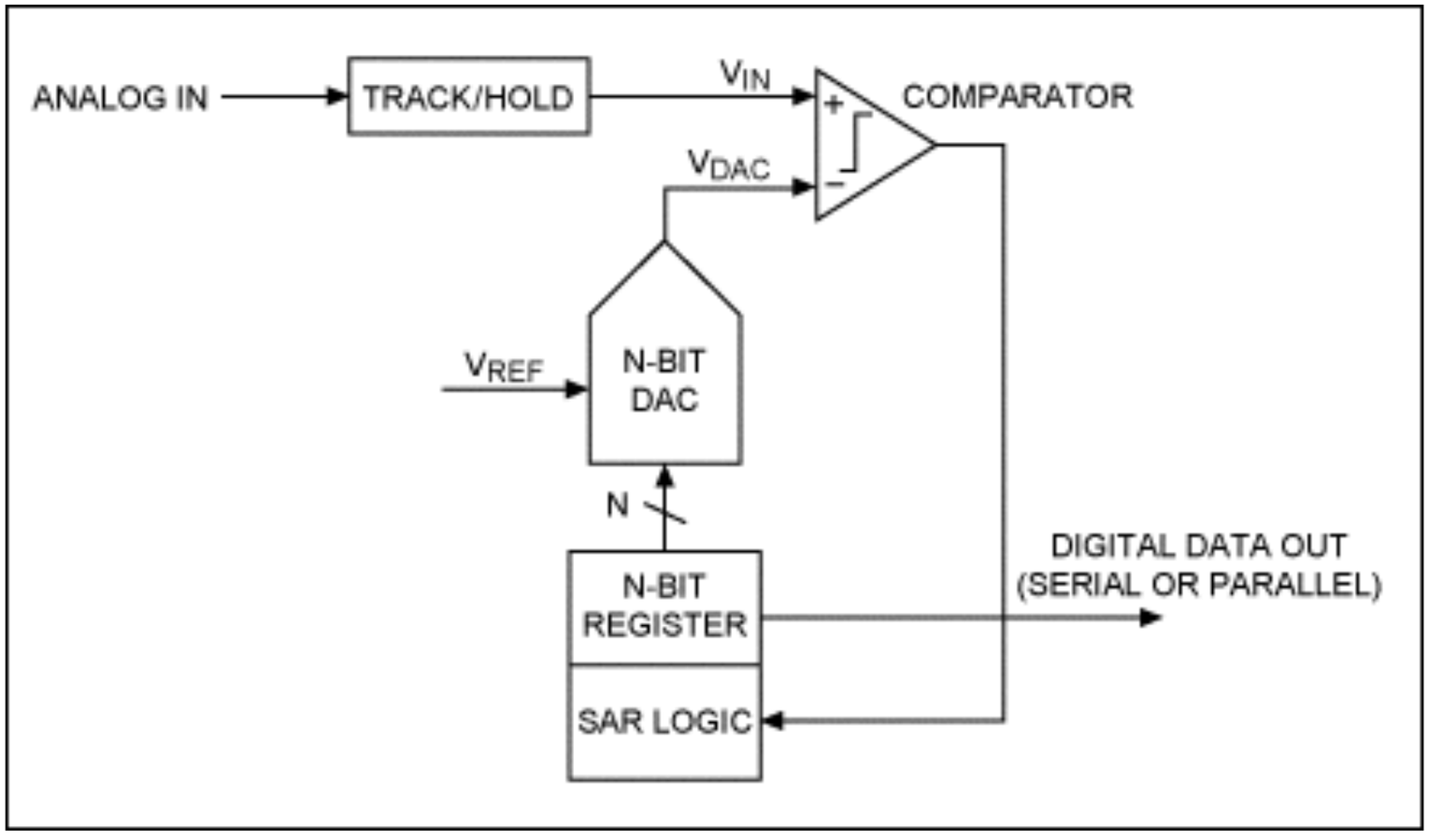
Flash ADC

- 高速，功耗大
- 分辨率 vs. 芯片面积—指数
- Vos 失调敏感



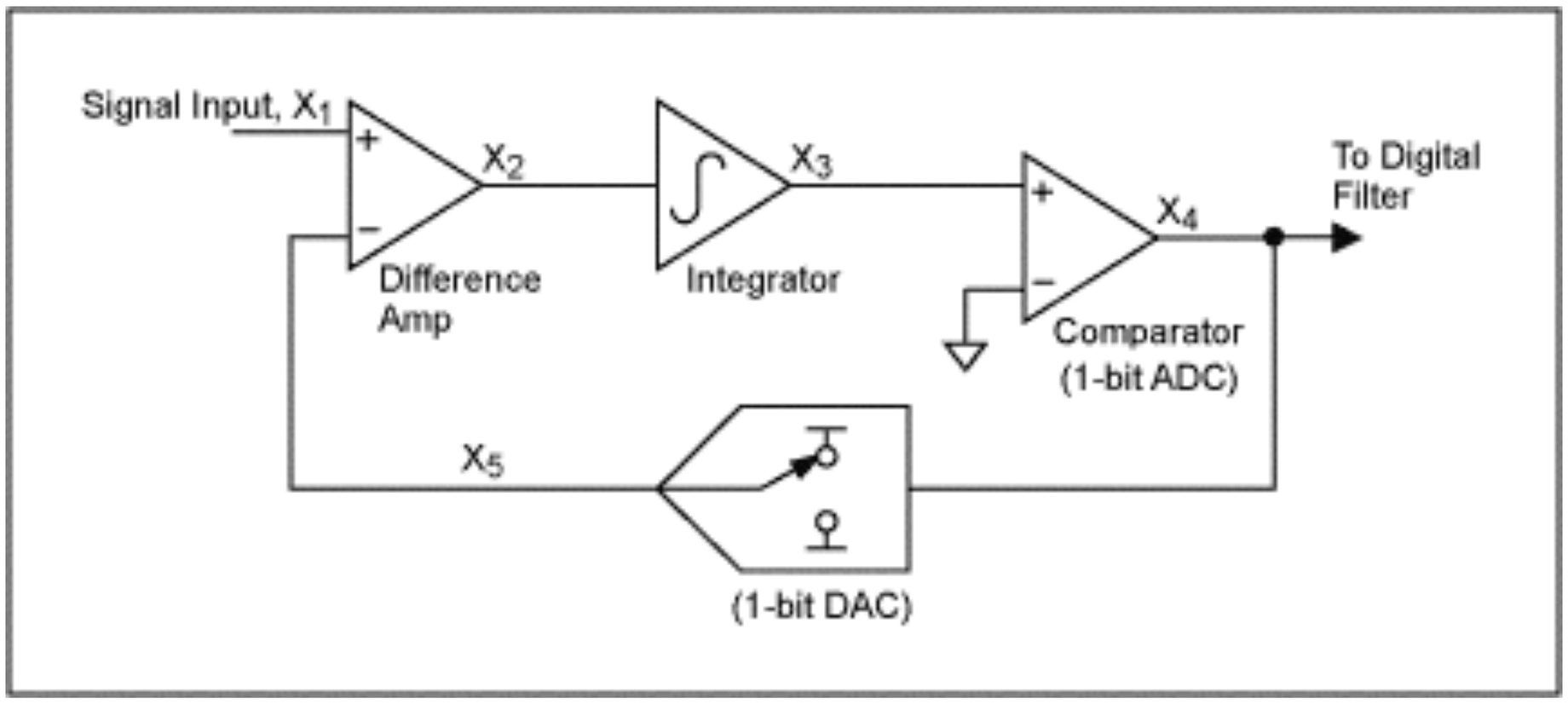
SAR ADC

- 速度中等，一般小于5MHz
- 低功耗／面积小
- 输入电路敏感



Delta – Sigma

- 一般速度低，精度高
- 速率換取分辨率



Pipeline

- 速率高，精度低
- 通常位数较低