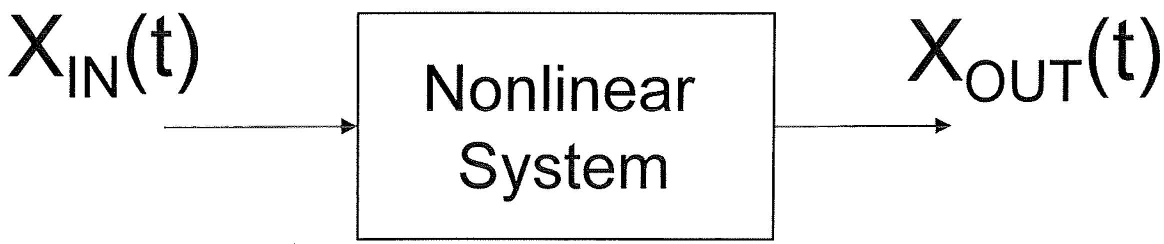
# Distortion Analysis




If

$$X_{IN}(t) = X_m \sin(2\pi f_a t + \theta)$$

$$X_{OUT}(t) = A_0 + \sum_{k=1}^{\infty} A_k \sin\left(2\pi k f_a t + \theta_k\right)$$

# Distortion Analysis

Total Harmonic Distortion, THD

$$\mathrm{THD} = \frac{\text{total power in all harmonic distortion components}}{\text{signal power or fundamental component power}}$$

$$\mathrm{THD} = \frac{A_2^2 + A_3^2 + A_4^2 + A_5^2 + \cdots + A_{20}^2}{A_1^2}$$

or 10 or 40

Signal to noise ratio:

$$\mathrm{SNR} = \frac{\text{signal power}}{\text{total power in all non-harmonic frequency bins}}$$

Signal to noise and distortion ratio:

$$\mathrm{SNDR} = \mathrm{SINAD} = \frac{\text{signal power}}{\text{total power in frequency bins except signal bin}}$$

in dB

ENOB = (SINAD-1.76)/6.02

effective # of Bits

# Distortion Analysis

Spurious free dynamic range:

$$\text{SFDR} = \frac{\text{signal power}}{\text{largest power in any frequency bin other than signal bin}}$$

In most cases, input signal is near full scale, and the largest spurious component is one of the harmonic distortion components:

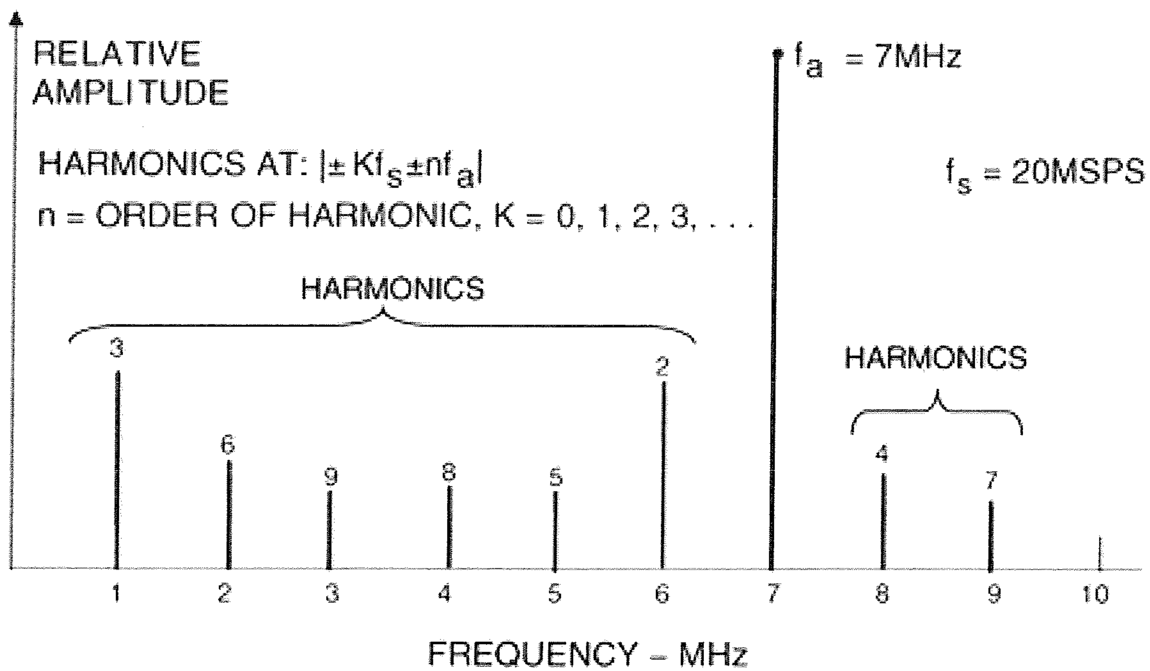
$$\text{SFDR} = \frac{\text{signal power}}{\text{largest harmonic distortion copmpnent power}}$$

$$\text{SFDR} = \frac{A_1^2}{\max_{k=2}^{\infty}\{A_k^2\}}$$

20 or 10

In dB, it is equal to the height difference between signal and the largest spur

# Harmonic distortion




fs=20MHz, fa=7MHz

1st = 7MHz

2nd = 2*7 = 14 = 20 – 6
= 6 MHz

3rd = 3*7 = 21 = 21 – 20
= 1 MHz

4th = 4*7 = 28 = 28 – 20
= 8 MHz

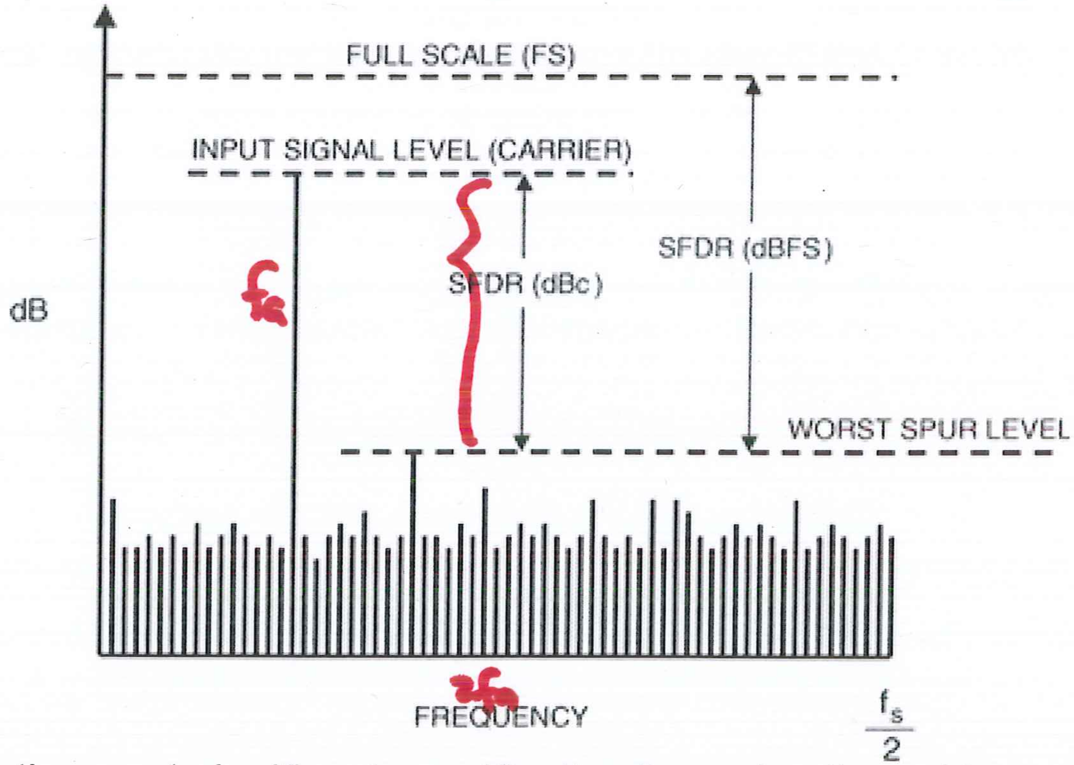
5th = 5*7 = 35 = 40 – 35
= 5 MHz

6th = 6*7 = 42 = 42 – 40
= 2 MHz

7th = 7*7 = 9 MHz

- *Harmonic distortion* is normally specified in dBc (decibels below *carrier*).
- Generally specified with an input signal near full-scale (generally 0.5 to 1 dB below full-scale to prevent clipping).

# Spurious Free Dynamic Range (SFDR)




- Probably the most significant specification for a circuit used in a communications application is its *spurious free dynamic range* (SFDR).
- SFDR is defined as the ratio of the signal power to the largest *spurious component power*..
- For input signal near full-scale, SFDR is generally determined by the largest harmonics
- For small input signals, other spurs, which are not harmonic to the input signal, may become larger that the harmonic distortion components.
- Therefore, SFDR considers *all spurs*, regardless harmonic or not.

In order to achieve a clean spectrum, need to main-tain "Coherent Sampling"

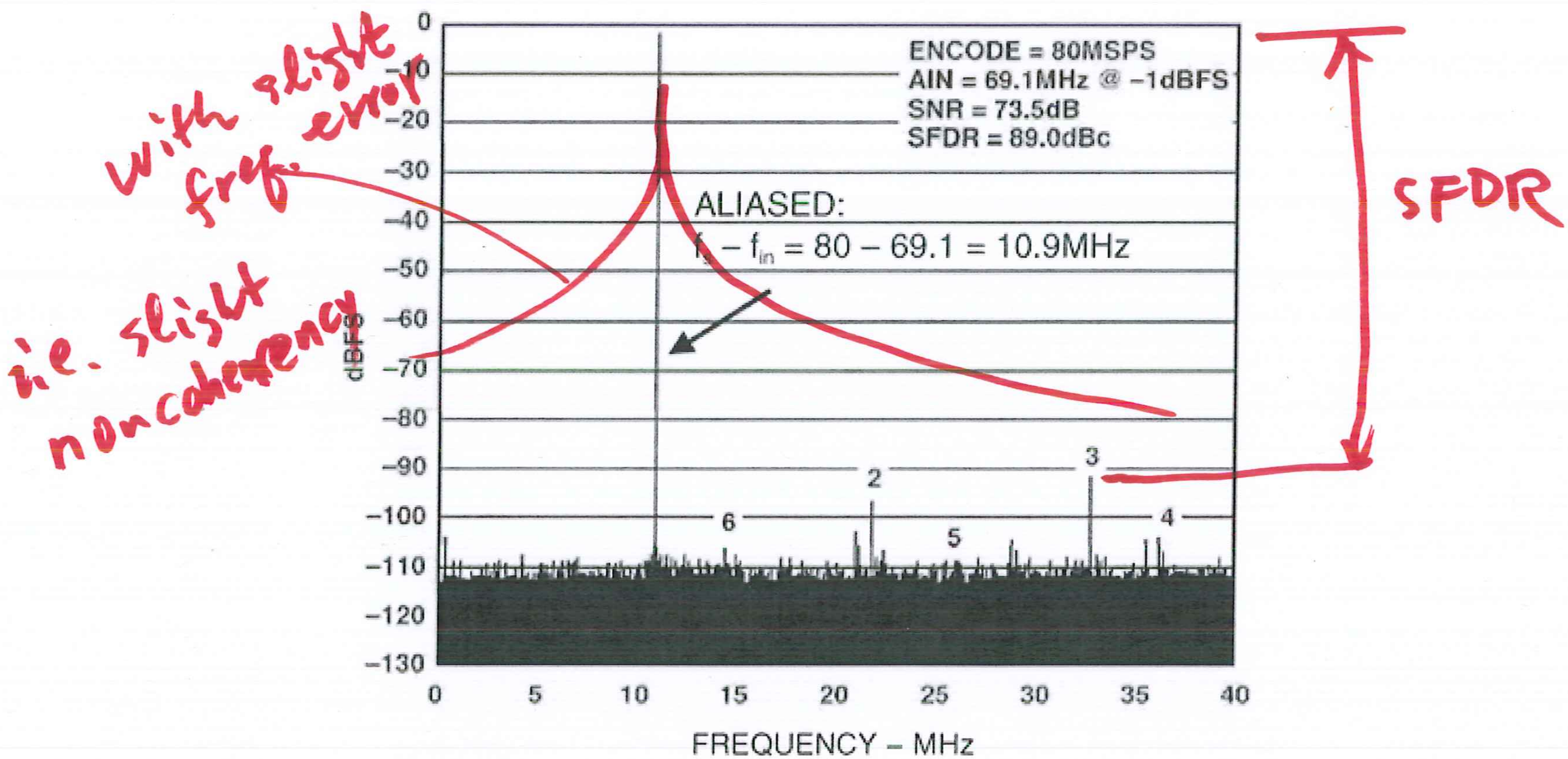
C.S ≡ the data set contain an exact integer # of periods.

$$\frac{f_a}{f_s} * M = \# \text{periods} = J$$ must be an integer

if $J = J_{int} + \Delta J$

& then, $\frac{\Delta J}{J_{int}}$ needs to be in $10^{-8}$, $10^{-9}$ range.

# Example SFDR with fs=80 MHz and fa=69.1 MHz




- 14-bit, 80 MSPS wideband ADC designed for communications applications
- single-tone SFDR for a 69.1 MHz input 89 dBc SFDR

Pick $M = 2^*$

pick $J$ = odd integer.

set sampling freq $f_s$.

Compute $f_a = \frac{J}{M} * f_s$

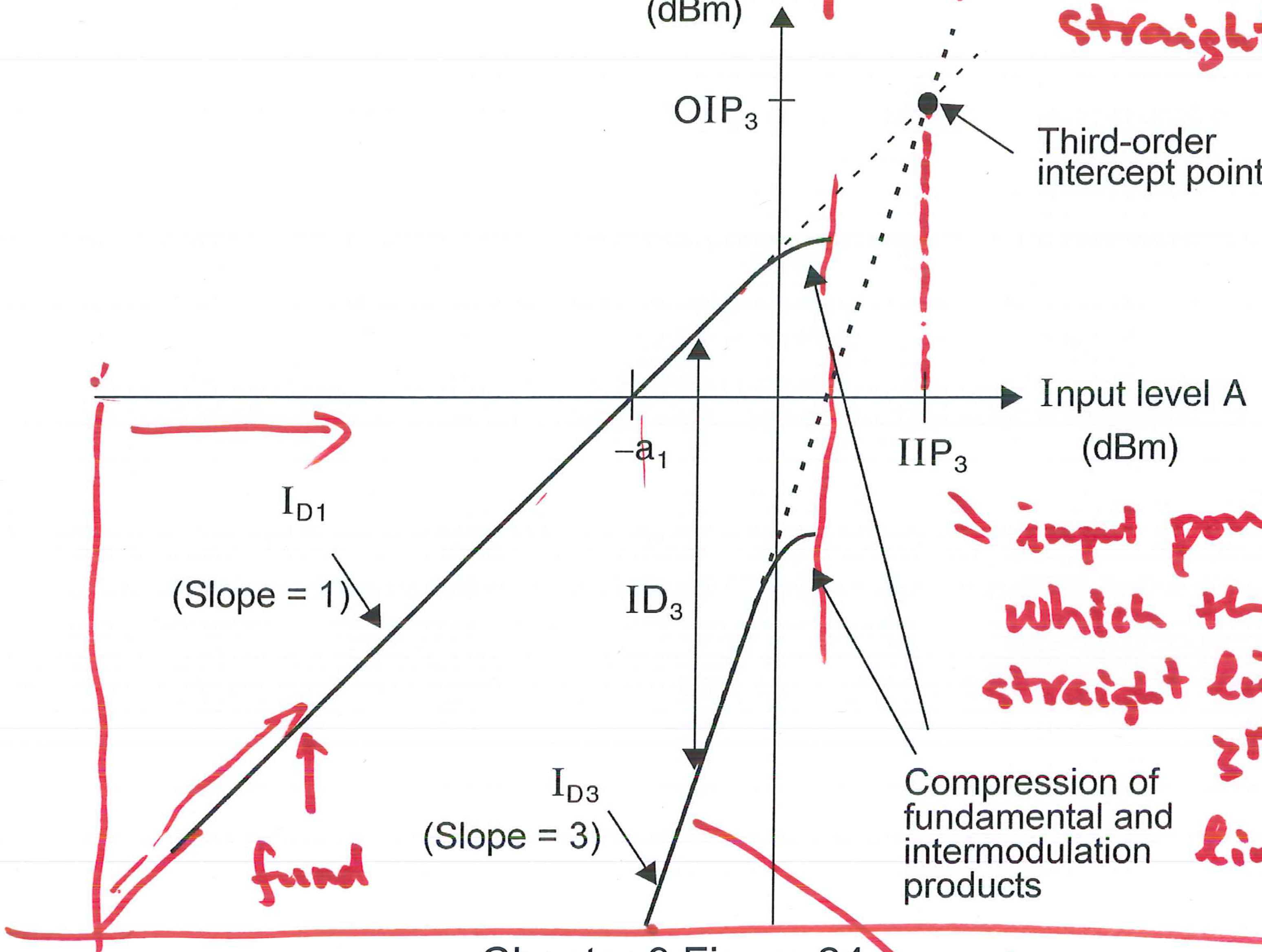
keep at least 8 or 9 effective digits.

```
M=4096; %#points in FFT
J=123;  %#periods of sine in M points
a = 1%logspace(-3,0,20)*1.5
    x=a*sin(2*pi*J*[0:M-1]'/M); %input pur sine wave
    y=LNA(x); %output of LNA
    yquant = round(y*2^(N-1))/2^(N-1); %quantized y
YFFT = 2*(abs(fft(yquant)/M)).^2;
YFFTdB = 10*log10(2^(-2*N)/1000000+YFFT);
Psig = YFFT(J+1);    YFFT(J+1)=0;
SFDR = 10*log10(Psig/max(YFFT(2:M/2)))];
HD=0;
for k=2:11, HD=HD+YFFT(J*k+1); YFFT(J*k+1)=0; end
Pnoise = sum(YFFT(2:M/2));
THD = 10*log10(HD/Psig);
SNR = 10*log10(Psig/Pnoise);
```

= $2^{12}$

Set fs, compute fa
apply fa sin input,
capture M points at
output.

−1 dB compression = input power at which output fund is 1 dB below straight line.



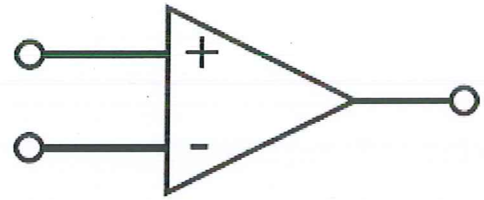

≥ input power at which the fund. straight line & the 3rd hd. str. line intersect

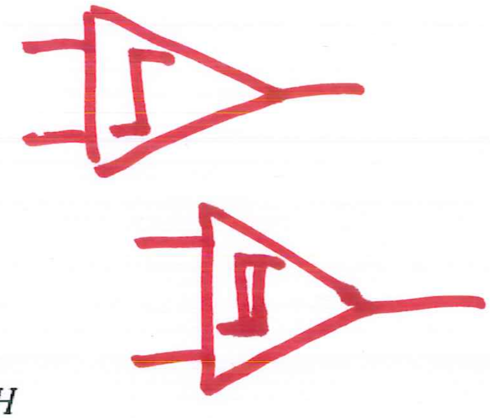
Chapter 9 Figure 24

# Comparator

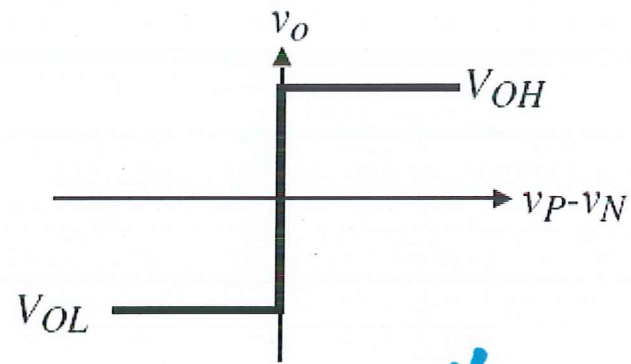
- **What is a Comparator?**
  - $2^{nd}$ most widely used building block after Op Amp
  - The comparator is essentially a 1-bit analog to digital converter.
    - Input is analog
    - Output is digital
  - Types of comparators:
    1. Open-loop (op amps without compensation)
    2. Regenerative (use of positive feedback - latches)
    3. Combination of open-loop and regenerative comparators

Circuit symbol:



Ideal I-O transfer curve




Actual I-O transfer curve