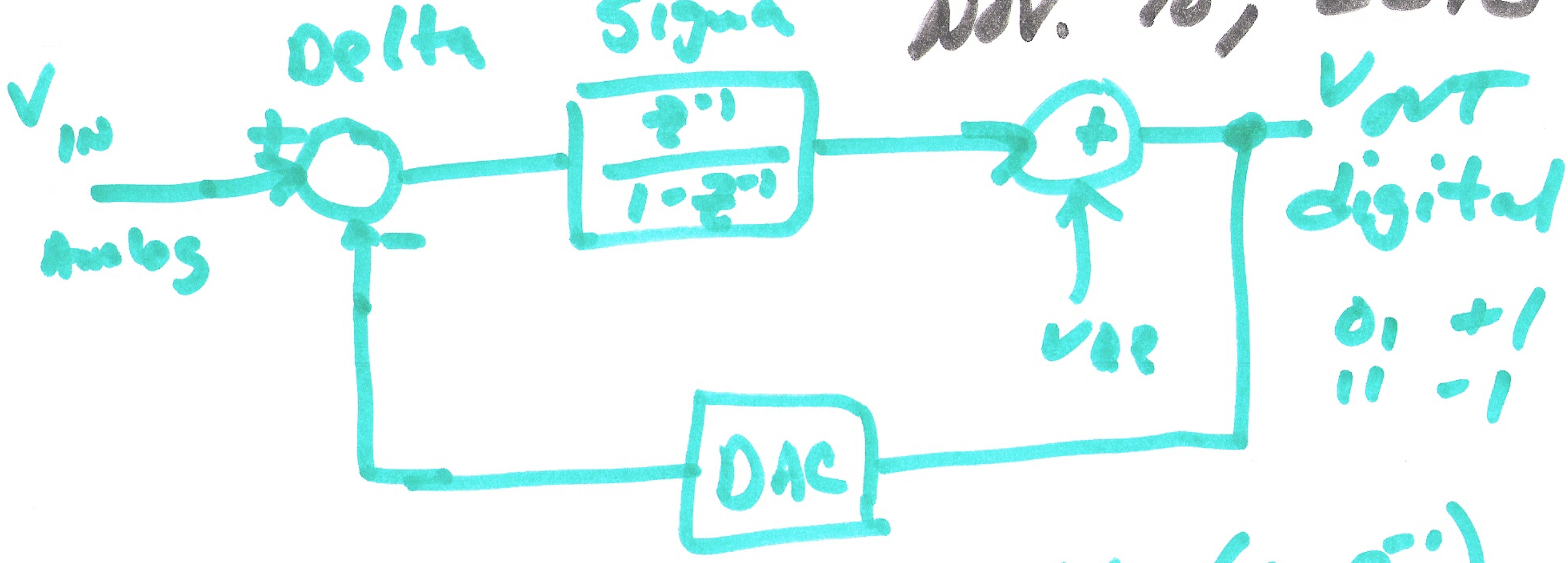
ECE 615 CMOS Mixed-Signal Circuit Design

Lecture 23, Nov. 10, 2010



$$V_{OUT} = z^{-1} \cdot V_{IN} + V_{QE}(1-z^{-1})$$

$$V_{OUT}[NTs] = V_{IN}[(N-1)Ts] + V_{QE}[NTs] - V_{QE}[(N-1)Ts]$$

$$2 \sin \pi f / f_s$$

$$NTF \cdot V_{QE} = \left(1 - e^{-j2\pi f \cdot T_s}\right) \cdot \frac{V_{LSB}}{\sqrt{12 f_s}}$$

$$V_{LSB} = \frac{V_{REF+} - V_{REF-}}{2^N}$$

$$0 \leq f \leq \frac{f_s}{2}$$

$$|NTF|^2 \cdot |V_{QE}|^2 = \frac{V_{LSB}^2}{12 f_s} \cdot 4 \cdot \sin^2 \pi \frac{f}{f_s}$$

$$RMS = 2 \int_0^B \frac{V_{LSB}^2}{12 f_s} \cdot 4 \cdot \sin^2 \pi \frac{f}{f_s} \cdot df$$

$$B = \frac{f_s}{2K} \qquad B << f_s$$

$$\sin x \simeq x$$

2)

$$\approx 8\,\frac{V_{LSB}^2}{12 f_s} \cdot \frac{\pi^2}{f_s^2} \underbrace{\int_0^B f^2\,df}_{\frac{1}{2} f^2}$$

$$V_{QE,rms}^2 = \frac{8\pi^2}{12} \cdot \frac{V_{LSB}^2}{f_s^3} \cdot \frac{B^3}{3}, \quad B = \frac{f_s}{2K}$$

$$= \frac{\cancel{8}\pi}{12} \cdot \frac{V_{LSB}^2}{\cancel{f_s^2}} \cdot \frac{\cancel{f_s^3}}{\cancel{8}K^3}$$

$$V_{QE,rms} = \frac{V_{LSB}}{\sqrt{12}} \cancel{\sqrt{\frac{\pi}{K^2}}} \frac{\pi}{\sqrt{3}} \cdot \frac{1}{K^{3/2}}$$

1-bit

$$SNR_{ideal} = 6.02N + 1.76 - 5.17$$

$$+ 30 \log K$$

first-order

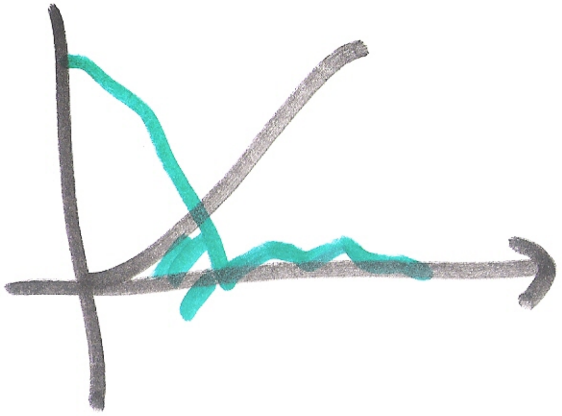
$$= 6.02(N + N_{inc}) + 1.76$$

1-bit

5-bits

$$N_{inc} = \frac{30 \log K - 5.17}{6.02}$$

$K=8$ 3.64 bits → 4 bits



$$\frac{1-z^{-8}}{1-z^{-1}} \rightarrow \log_2 K = 3\text{-bits}$$

4)

L = # Sinc filters we cascade

$$L \cdot \log_2 K \geq \frac{30 \log K - 5.17}{6.02}$$

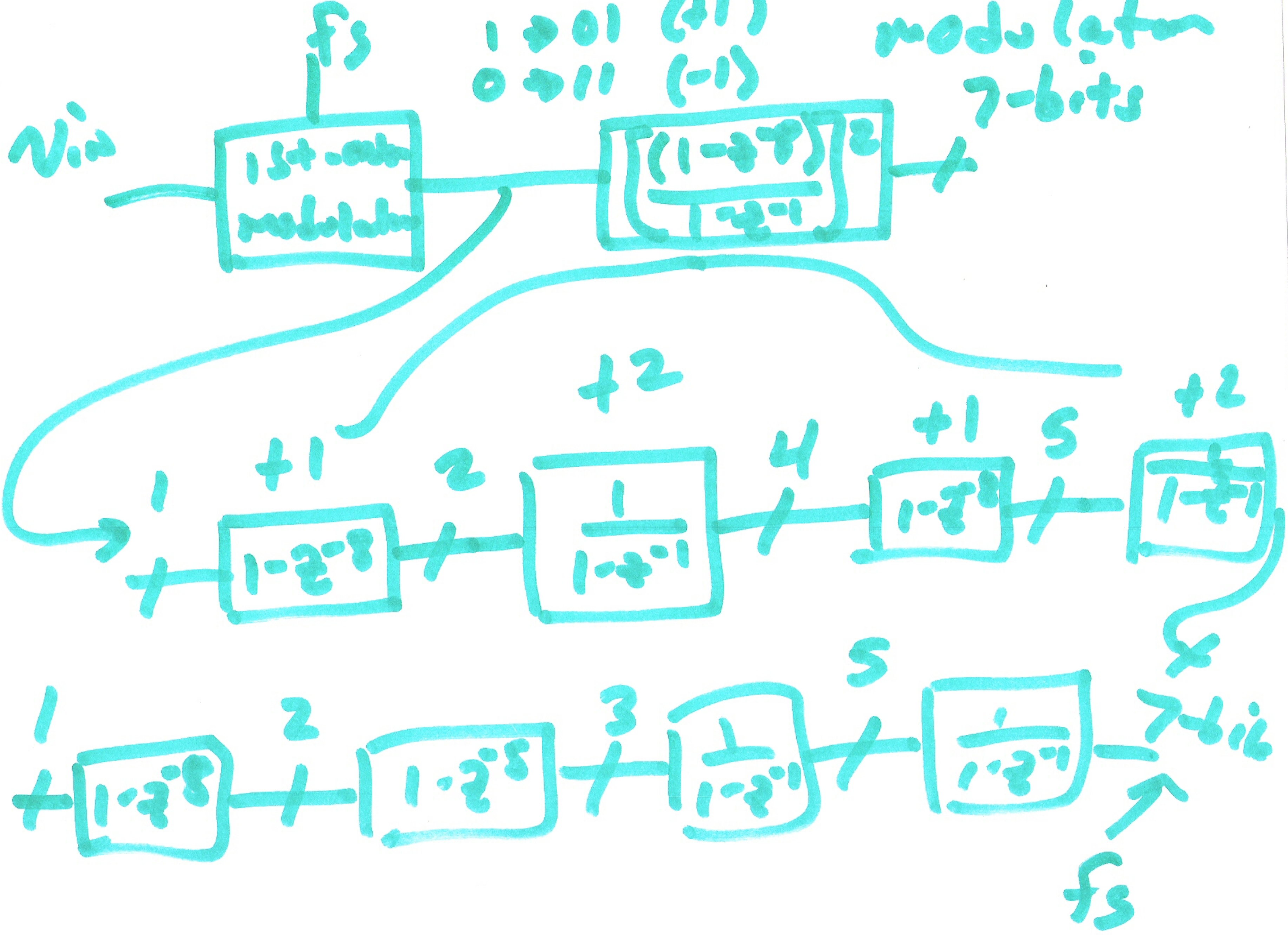
M = order of the modulation

M = 1 (first order)

L = M + 1

5)

Filtering output of 1st-order modulator



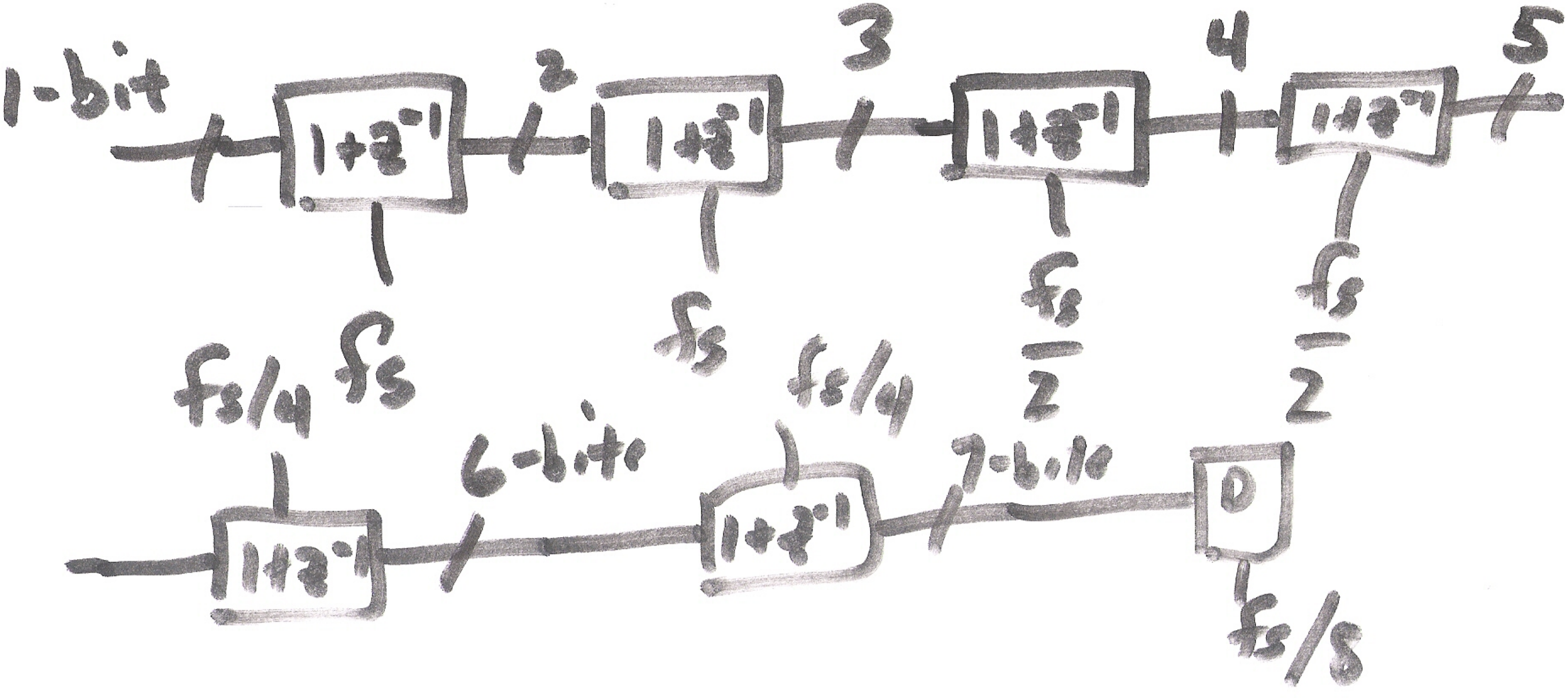
1st-order modulator K = 8

$$\left[\frac{1-z^{-8}}{1-z^{-1}}\right]^2$$

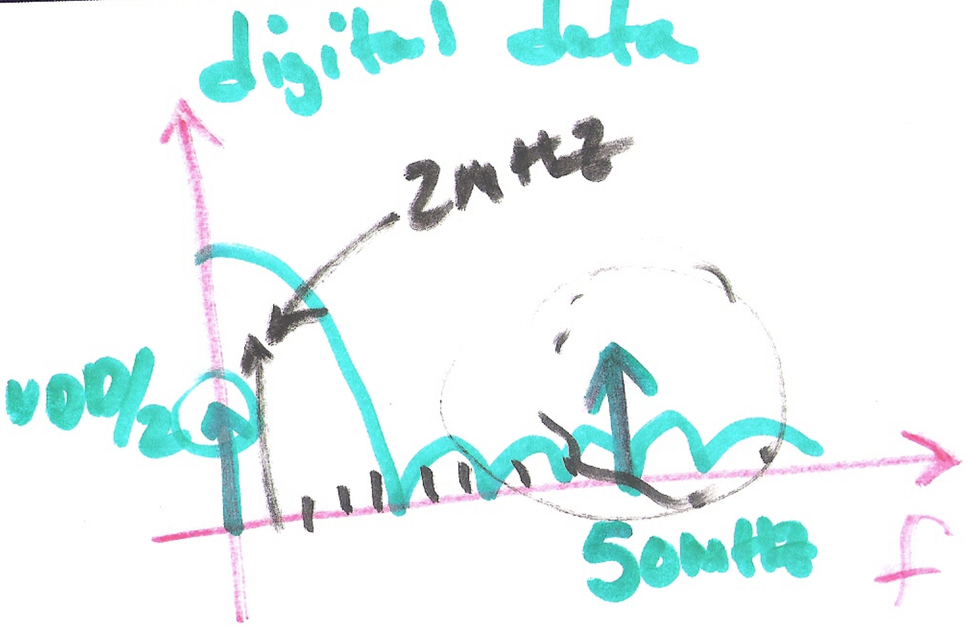
L = 2

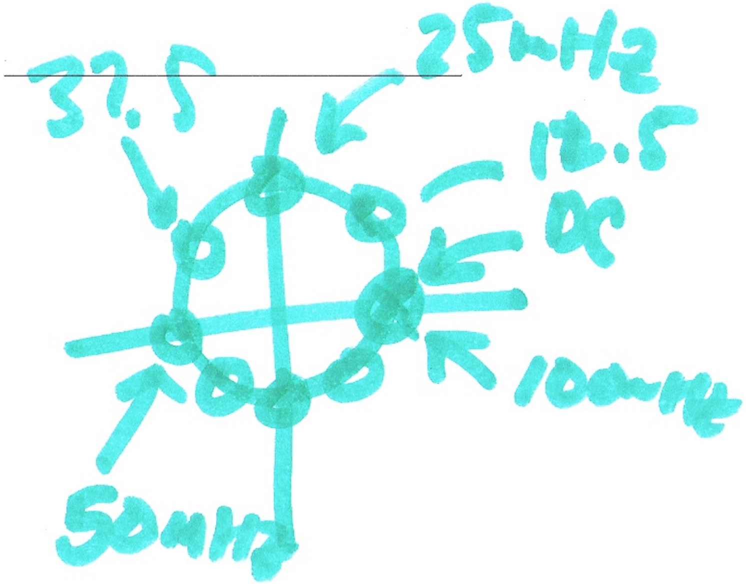
M = 1

mixing decimation & filtering



Limit cycle oscillations

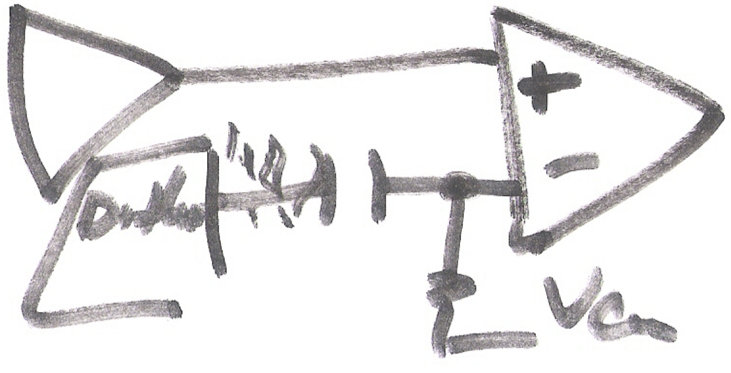




k=8

→ 11 01010101 11 01 0101 → .51V

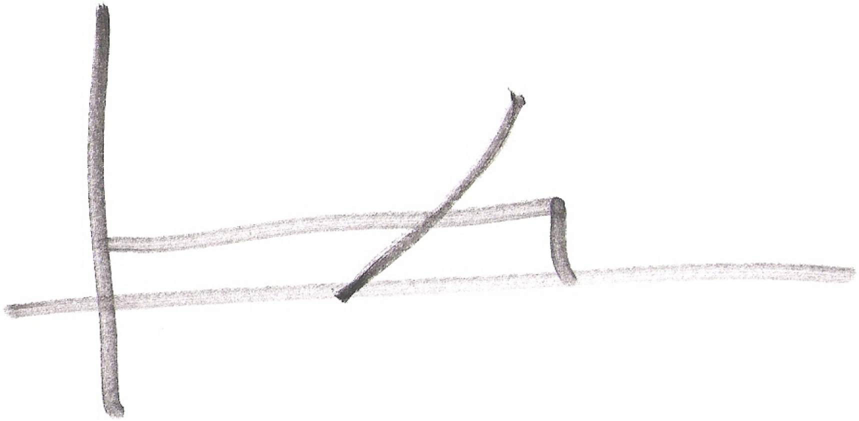
11 01011100 101011

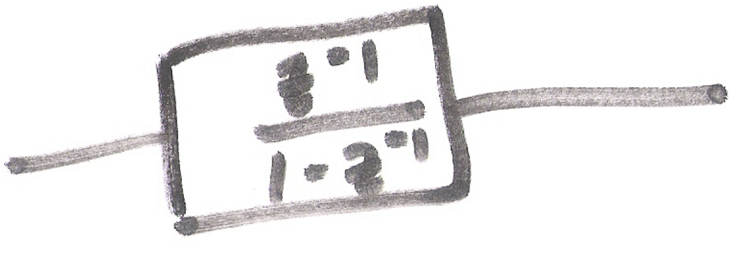


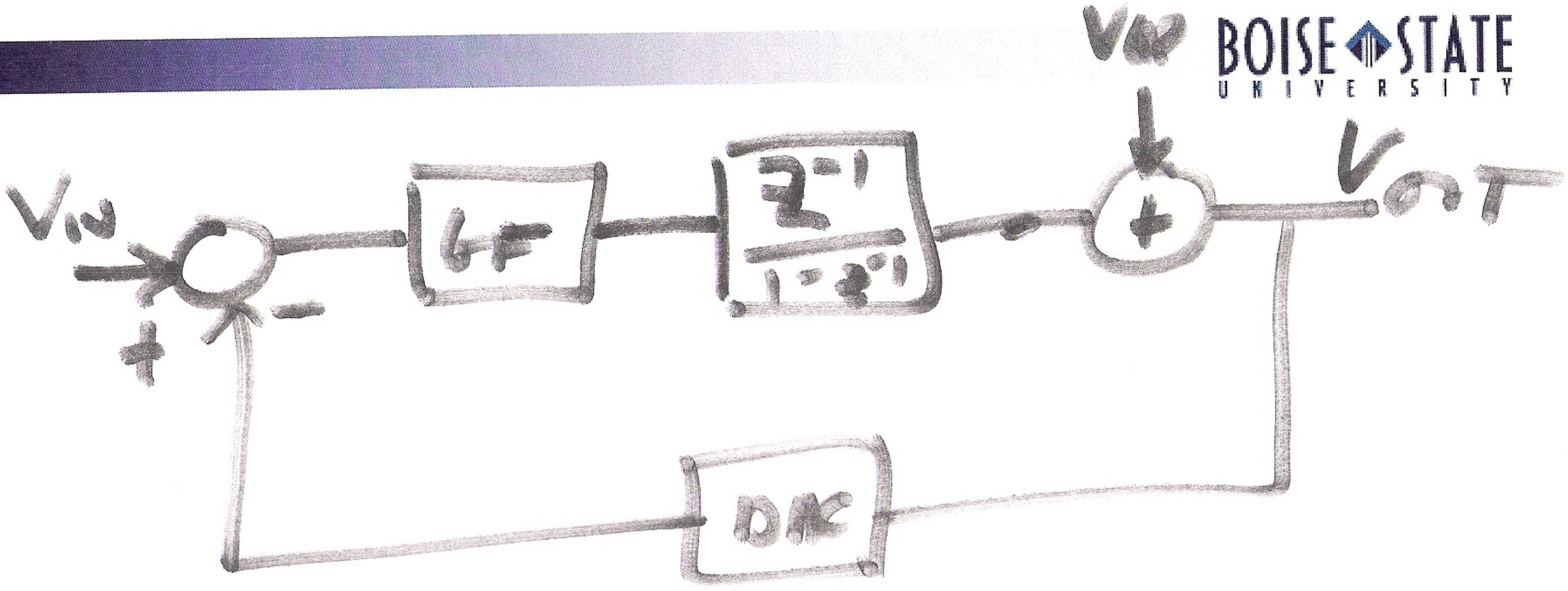
8)

say you add a noise dither

$$V_{OUT} = (V_{IN} + V_{dither})z^{-1} + (V_{Qe} + V_{dither})(1 - z^{-1})$$





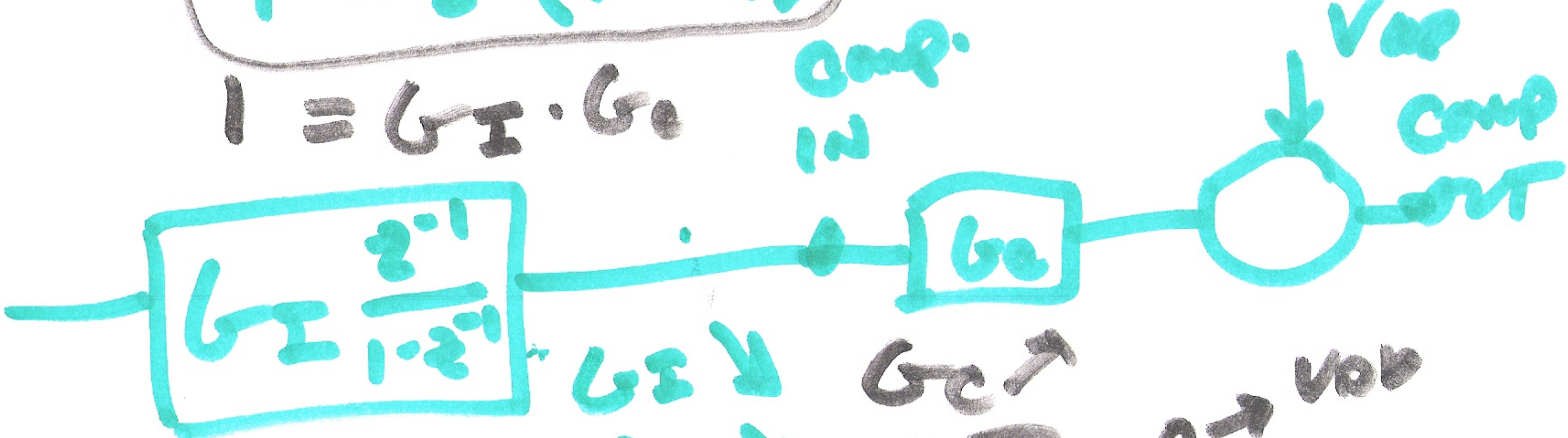


$$(V_{IN} - V_{OUT})\, G_F \cdot \frac{z^{-1}}{1-z^{-1}} + V_{QE} = V_{OUT}$$

$$V_{OUT}(1-z^{-1}) + V_{OUT}\, z^{-1} G_F =$$
$$V_{IN} \cdot G_F z^{-1} + V_{QE}(1-z^{-1})$$

$$V_{AT} = \boxed{\frac{V_{IN}\,G_F\,z^{-1}}{1 - z^{-1}(1-G_F)}} + \frac{V_{OP}(1-z^{-1})}{1-z^{-1}(1-G_F)}$$

$1 = G_I \cdot G_C$

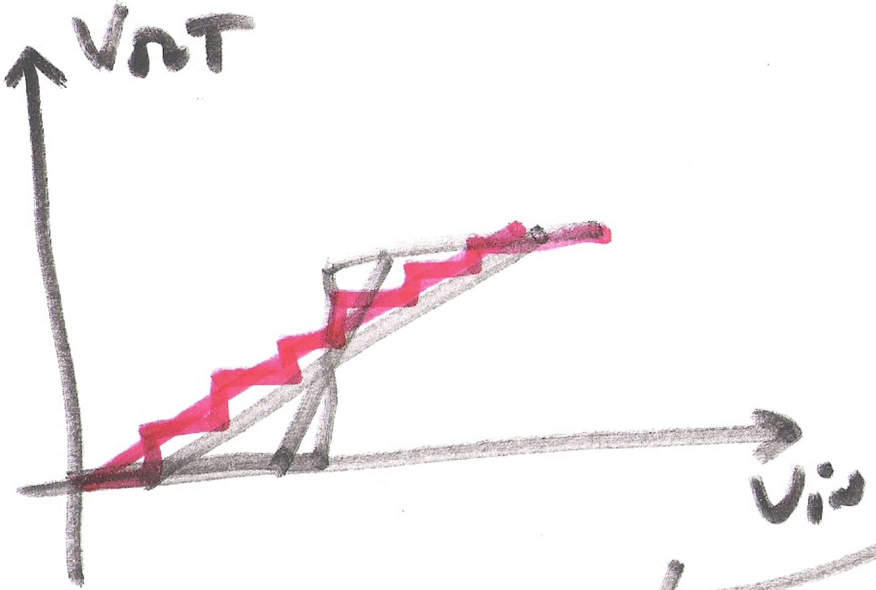


G_I ↓ G_C ↗

swing ↓ V_{AT} 0 → VDD

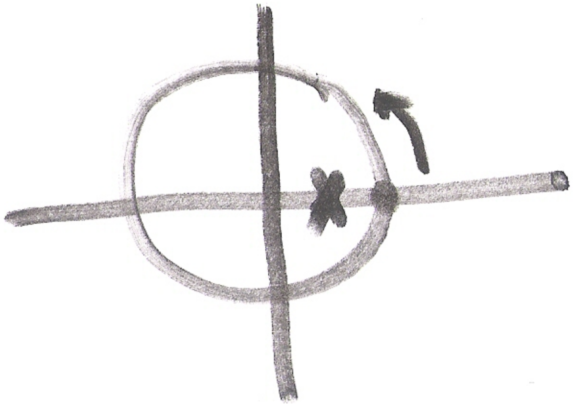
$$G_I = \frac{C_I}{C_F}$$

problems with multi-bit quantizers

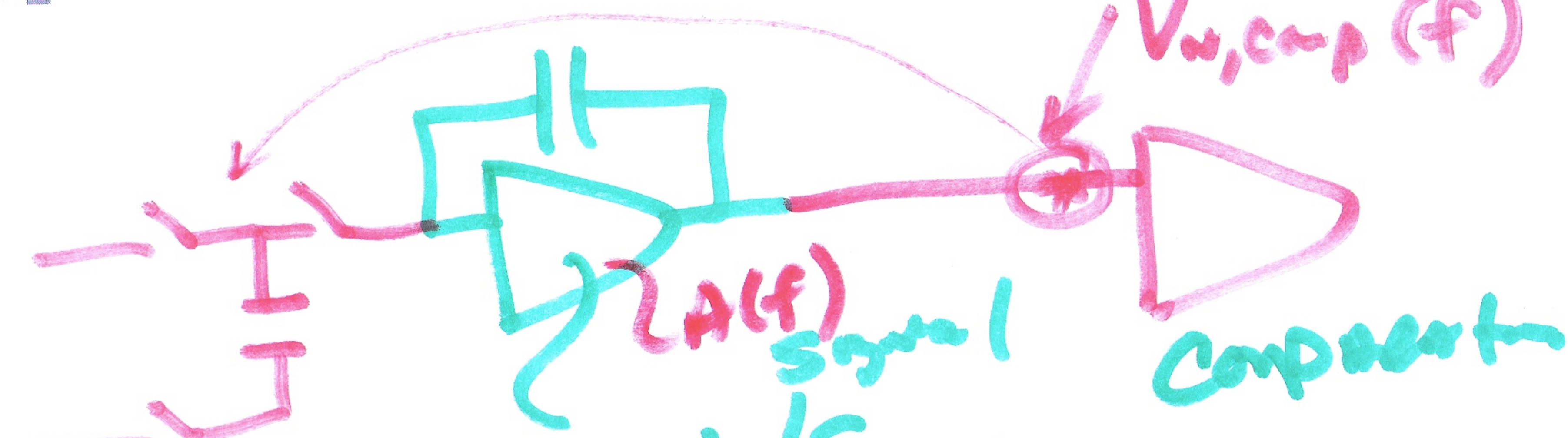


GF ≠ 1   GF = 1/2

$$\underbrace{\frac{\frac{1}{2}}{z-\frac{1}{2}}}_{STF}$$



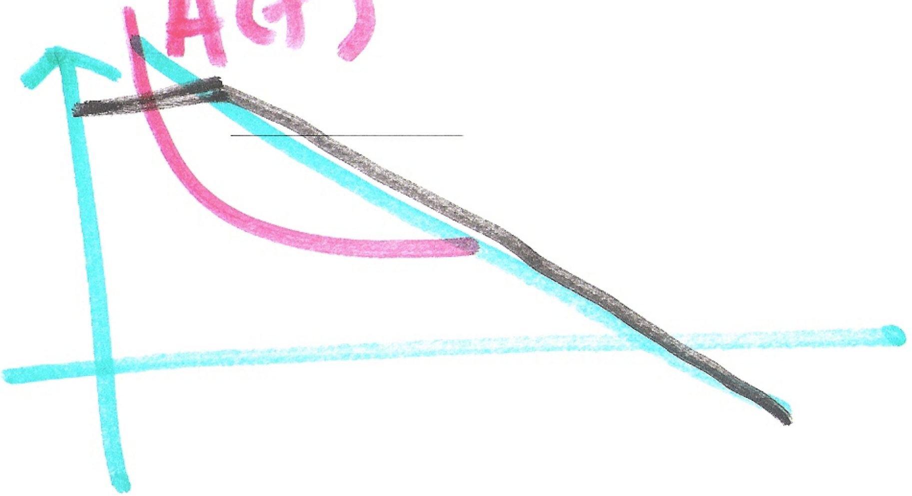
Comparator gain, offset, hysteresis



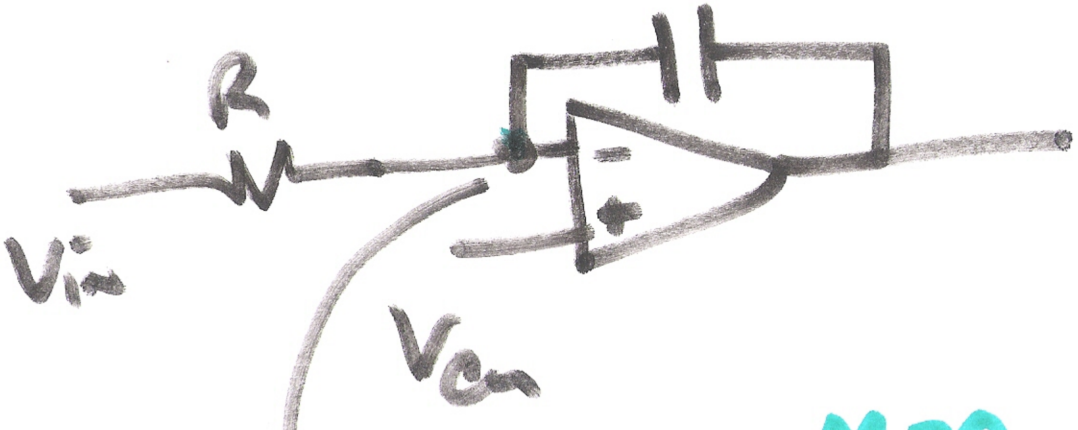
Gain High in signal freque. is A(f)

Vin
↘

$$\frac{V_{in,comp}(f)}{A(f)}$$

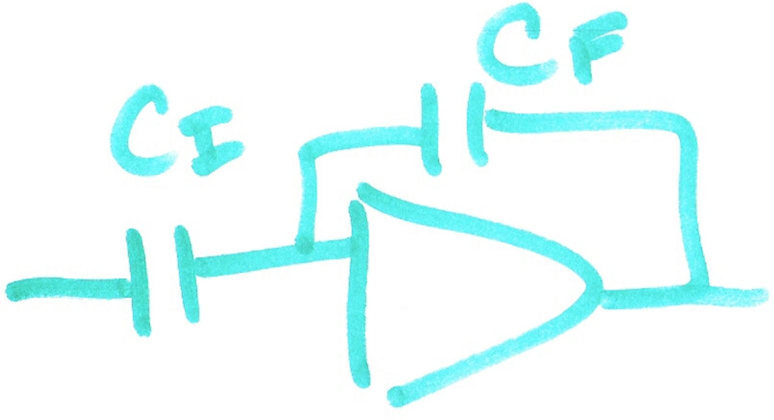


Op-Amp gain



$$\Delta V_{OUT} = A_{OL} \cdot \left(\underset{0}{\cancel{V_+}} - \cancel{V_-}\right)$$

$$V_- = \cancelto{AC=0}{V_{cm}} + \frac{\Delta V_{OUT}}{A_{OL}}$$



$$\frac{C_I}{C_F}$$

$$\underbrace{\frac{z^{-1}}{1 + \underbrace{\frac{C_I}{C_F} \cdot \frac{1}{A_{OL}}}_{E_{gain}}}}_{STF} \cdot V_{in}$$

$A_{OLDC} \geq K$ (oversampling)

op-amp DC gain

$f_{un} \geq K \cdot B = \frac{f_s}{2}$